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INSTITUUT SEEVISSERYE

FISHERIES BULLETIN

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VISSERYE — BULLETIN

CONTRIBUTIONS TO OCEANOGRAPHY AND FISHERIES
BIOLOGY

BYDRAES TOT OSEANOGRAFIE EN VISSERYBIOLOGIE

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H.G. v. D. Boonstra

and/en

A.I.L. Payne

Artwork by/Kunswerk deur

M.A. Herbert

M.B. van der Linde

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SMALL-SCALE MEASUREMENTS OF VERTICAL SHEAR AND RATES OF HORIZONTAL DIFFUSION IN THE SOUTHERN BENGUELA CURRENT

A. J. BOYD

A large biplanar drogue was deployed at a depth of 10 m in cool upwelled water off the Cape Peninsula and followed for a week by R.S. *Africana II*. Smaller drogues were released around this drogue at depths of 2, 10 and 20 m and tracked from an inflatable boat to observe diffusion and vertical shear of horizontal velocity. Mean rates of pair separation of $8,1 \text{ m}\cdot\text{h}^{-1}$, $7,0 \text{ m}\cdot\text{h}^{-1}$ and $7,1 \text{ m}\cdot\text{h}^{-1}$ were obtained for drogues released at 2, 10 and 20 m respectively. An eddy diffusivity of $190 \text{ cm}^2\cdot\text{s}^{-1}$ was estimated from these data. The average shear speed between 2 and 10 m, and 10 and 20 m, was $1,25$ and $0,8 \text{ cm}\cdot\text{s}^{-1}\cdot\text{m}^{-1}$ respectively. On one occasion, a well-defined explosive phase of horizontal diffusion was observed, and scales were obtained which yielded an estimate of eddy diffusivity of $2,2 \times 10^4 \text{ cm}^2\cdot\text{s}^{-1}$ for this phase. Based on the mean data a conservative model of dispersion was derived. This model showed that a 2-m-thick patch of particles centred 10 m deep would rapidly stretch horizontally from 10 m to hundreds of metres along the axis of shear in a period of hours, whilst diffusion operated on a scale an order of magnitude less.

'n Groot tweevlakkige dryfanker, gestel vir 'n diepte van 10 m, is in koel opgewelde water langs die kus van die Kaapse Skiereiland losgelaat, en is 'n week lank deur die NS. *Africana II* gevolg. Kleiner dryfankers, gestel vir dieptes van 2, 10 en 20 m, is rondom hierdie dryfanker losgelaat en van 'n opblaasbare boot af nagespoor om uitspreiding en vertikale verskille in horisontale snelheid waar te neem. Gemiddelde paar-skeidingskoerse van $8,1 \text{ m}\cdot\text{h}^{-1}$, $7,0 \text{ m}\cdot\text{h}^{-1}$ en $7,1 \text{ m}\cdot\text{h}^{-1}$ is verkry vir dryfankers wat onderskeidelik op 2, 10 en 20 m losgelaat is. 'n Malingsdiffusiekoëffisiënt van $190 \text{ cm}^2\cdot\text{s}^{-1}$ is volgens hierdie gegewens geraam. Die gemiddelde grootte van vektorverskil tussen 2 en 10 m, en 10 en 20 m, was onderskeidelik $1,25$ en $0,8 \text{ cm}\cdot\text{s}^{-1}\cdot\text{m}^{-1}$. Een keer is 'n goed gedefinieerde eksplousiewe fase van horisontale uitspreiding waargeneem, en verkreë skale het vir hierdie fase 'n malingsdiffusiekoëffisiënt van $2,2 \times 10^4 \text{ cm}^2\cdot\text{s}^{-1}$ gelever. Die gemiddelde gegewens het gedien as grondslag vir 'n konserwatiewe model van verspreiding. Die model het aangetoon dat 'n kol partikels 2 m dik wat op 10 m gesentreer is, vinnig horisontaal sou uitrek, van 10 m tot honderde meter met die spil van die skuifsnelheide langs, binne 'n tydperk van ure, terwyl uitspreiding 'n grootteorde laer gegradeer was.

The method of repeated hydrobiological sampling in the vicinity of a drogue set at a certain depth to monitor changes in what is hoped to be the same body of water has been applied a number of times off the Cape Peninsula (Andrews and Cram 1969, Olivieri 1981, Shelton and Hutchings 1982, and in five drogue studies undertaken by the Sea Fisheries Institute between December 1979 and October 1981). During the cruise in October 1981, measurements of rates of horizontal diffusion and of vertical current shear were made with the objectives of ascertaining firstly to what extent the same body of water was indeed being followed, and secondly the typical scales involved in the dispersion processes operative around the drogue. The results of this work are reported here.

MATERIALS AND METHODS

A biplanar tetrahedral drogue with sides 4 m long was deployed 10 m deep at 08h00 on 20 October 1981 in a patch of cool newly upwelled water 4 miles west of the Cape Peninsula. This drogue was followed by R.S. *Africana II* for the next seven days and its

position was fixed every hour (Fig. 1). R.S. *Sardinops* occupied hydrobiological and current-metering stations once per day normal to the coast, across the track of the large drogue. Hydrobiological and productivity determinations were carried out from R.S. *Africana II* three times daily as near as possible to the drogue, and six 1-m biplanar drogues were released from a small inflatable craft around the larger drogue at depths of 2, 10 and 20 m. The movements of these drogues were obtained relative to each other and to the larger 10-m drogue by means of a visual range-finder and a directional monocular. Readings were made over periods of up to two hours between 08h00 and 10h00, 12h00 and 14h00, and 15h30 and 17h30 each day.

For five days, pairs of drogues were released at depths of 2, 10 and 20 m, and measurements were made of rates of pair separation for these depths and of the shear velocities between 2 and 10, and 10 and 20 m. For the remaining two days, four drogues were released at 10 m and one each at 2 and at 20 m. Thus, both shear velocities and a more comprehensive picture of horizontal separation rates at 10 m, the depth of the large drogue followed by R.S. *Africana II*, could be obtained. On these occasions the drogues at 10 m were allowed to drift for eight hours before

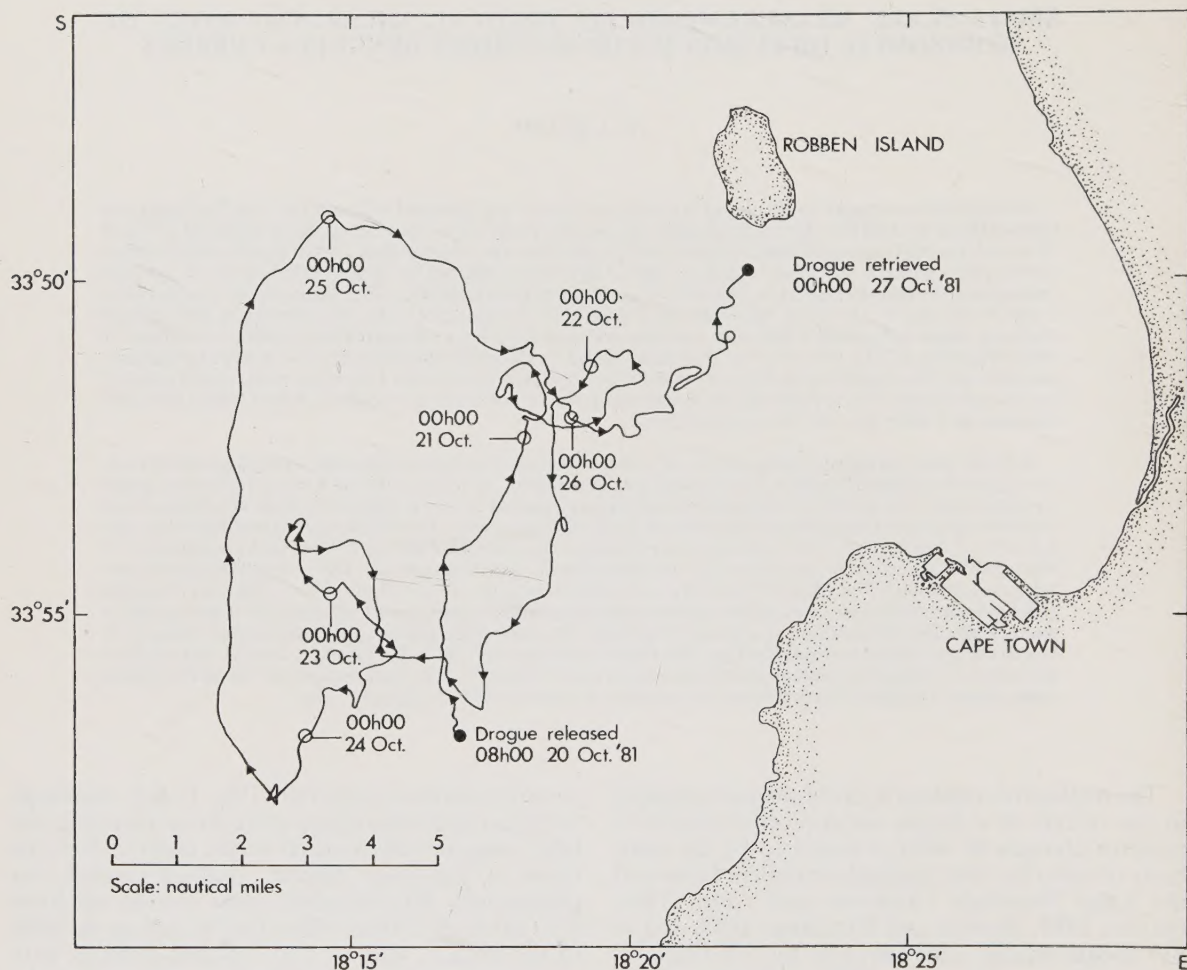


Fig. 1: Track of the 10-m drogue between 08h00 on 20 October and 00h00 on 27 October 1981

being retrieved.

The shear and separation measurements suffered different degrees of uncertainty, largely because of the design of the range-finder. This instrument is graduated in 1-m steps to 20 m, 2-m steps to 40 m, 5-m steps to 70 m, 10-m steps to 100 m and thereafter at 120, 150, 200, 300, 500 and 1 000 m. Whereas these graduations do not determine the accuracy of measurement because of interpolation between graduations, in practical terms they reflect the field accuracy. Therefore, separation measurements which were typically concerned with distances less than 50 m have an uncertainty of the order of ± 2 m, whereas shear measurements which were conducted

over distances between 150 and 300 m suffer possible error of the order of 20 per cent. Furthermore, no correction was made for the fact that land-based tests showed the instrument to be consistently overestimating distances by 4 per cent. Results from a subsequent experiment showed that the standard deviation from the mean of a single directional monocular reading was, on average, less than 4° .

Windage on the part of the drogues above the water (i.e. a 1-m-long aluminium pole with a small identifying flag) was estimated by means of the method given in Murray (1975). The error due to windage thus calculated was found to be less than $1 \text{ cm} \cdot \text{s}^{-1}$ in a wind of 20 knots, and therefore no

corrections to the data set were deemed necessary. Windage error would not influence the slow pair-separation rates in any case, because the drogues used were identical.

RESULTS

Large-scale features

The trajectory of the 10-m drogue, which is shown in Figure 1, was used to obtain 4-hourly mean velocity vectors for the current 10 m deep. The measured velocities of the currents at 2 and 20 m relative to that at 10 m were added vectorially to the latter to obtain absolute velocity vectors for the currents at 2 and 20 m. These vectors are shown in Figure 2, together with bathythermograph and wind data for the period 20–26 October.

From Figures 1 and 2, it is clear that only on 24

October did the current velocity at 10 m remain relatively uniform for a period longer than 12 hours. This can be attributed to a southerly wind of 40 hours' duration which caused the upper layer (to 20 m deep) to move in a northerly direction parallel to the general lie of the coast. For the remainder of the cruise, which included two days of sustained northerly winds, the currents at 2, 10 and 20 m were irregular, although some response to the wind-forcing can be noted from Figure 2.

The temperature of the upper 30 m rose by approximately 1°C between 20 and 26 October (Fig. 2). If it were not that the data showed marked current shear of the order of 1 cm·s⁻¹·m⁻¹ in the upper 20 m (Table I) the temperature record would seem to indicate that the same body of water had been followed at depths other than 10 m (cf. the conclusion of Andrews and Cram 1969). Further implications of the recorded speeds of current shear will be discussed later.

Results from current-metering undertaken across the track of the 10-m drogue every day by R.S. *Sardinops* confirm the reversals in the drogue track and indicate that the current field was highly variable in space as well as time (C.J. Holden, Sea Fisheries Institute, personal communication). Although the accompanying vertical temperature sections did not show any marked variation in the horizontal, five-fold changes in the concentration of chlorophyll *a* were noted over as little as 5 km on occasion. Concentration varied by as much as ten-fold in 10 m in the vertical (L. Hutchings, Sea Fisheries Institute, personal communication).

Small-scale features

The data dealing with the horizontal separation of drogues at fixed depths are presented in two forms.

Firstly, Figure 3 shows the diffusion of four identical drogues 10 m deep from 08h00 to 17h00 on 24 October, during which period the ensemble of drogues moved northwards with a consistent speed averaging 26 cm·s⁻¹. Relative to each other, the drogues remained within a 100-m square for the first 4 hours, before separating to almost fill a 250-m square in the next 1¼ hours. This accelerated separation was not maintained over the following 3 hours, however, all drogues still being confined to a 250-m square 8 hours after deployment. On 25 October, the ensemble described a semi-circular track and no accelerated diffusion was recorded, all drogues remaining within 100 m of each other after 6 hours' drifting.

Secondly, Tables II and III present relationships

Table I: Current speeds and shear speeds in the upper 20 m

Date — Oct. 1981 and (Time)	Current speeds (cm·s ⁻¹)			Shear speeds (cm·s ⁻¹)		
	2 m	10 m	20 m	2-10 m	10-20 m	2-20 m
20 (09h00)	22	20	17	5	8	13
(13h00)	26	18	12	8	7	15
(17h00)	22	16	13	8	3	11
21 (09h00)	5	5	4	1	6	6
(13h00)	35	14	12	22	7	28
(17h00)	28	15	6	13	20	31
22 (09h00)	13	15	19	12	4	13
(13h00)	13	12	—	14	—	—
(17h00)	6	6	11	12	7	17
23 (09h00)	15	10	12	11	12	23
(13h00)	6	16	19	10	4	14
(17h00)	24	18	18	10	0	10
24 (09h00)	29	23	20	9	6	16
(13h00)	18	27	31	9	9	17
(17h00)	24	27	30	2	4	6
25 (09h00)	33	19	21	13	22	30
(13h00)	21	8	8	15	16	28
(17h00)	8	8	12	15	5	19
26 (09h00)	17	11	10	7	5	12
(13h00)	15	11	11	9	2	7
(17h00)	13	8	3	6	5	11
Mean	19	15 (14)*	14	10	8	16
Std dev. <i>n</i>	9 21	6(8)* 21 (39)*	8 20	5 21	6 20	8 20

* Figures in brackets include 21h00, 01h00 and 05h00 measurements available only for the 10-m drogue

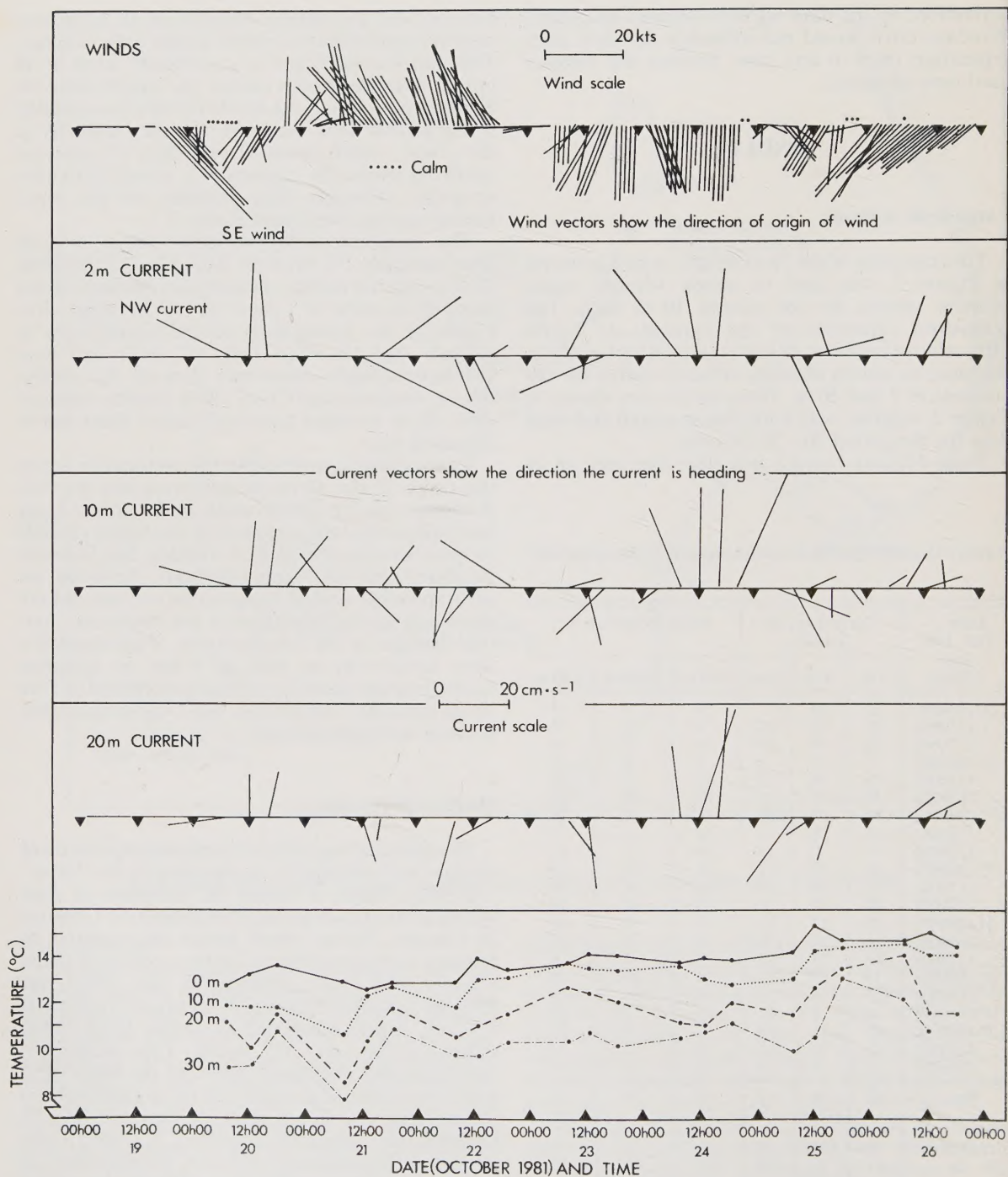


Fig. 2: Wind and current vectors and bathythermograph data

Table II: Correlations between mean drogue separation l , the standard deviation of l and the time elapsed since deployment for drogues at 10 m

Time (minutes)	Mean drogue separation l (m)	Standard deviation of l (m)	n
20	7,4	2,6	14
40	9,8	3,7	15
60	11,5	4,6	14
80	15,2	5,5	12
100	15,8	7,3	9
120	20,7	11,6	7
Correlation with time r	0,98	0,94	6
Slope m ($m \cdot h^{-1}$)	7,5	4,9	—

between drogue-pair separation and time, for the period until 2 hours after deployment of the drogues. Data for the seven days from 20 to 26 October were combined for this purpose, because no other data grouping could be justified on the basis of conditions and currents experienced. Individual pair separations with time were interpolated linearly and then redigitized at 20-minute intervals to standardize the data. Unfortunately, not all tracking events lasted for the full 2 hours.

The data in Table II show that both the mean pair separation and its standard deviation increased linearly with time. The latter relationship dictated that pair separations should be weighted before regression against time. The procedure employed to calculate the data in Table III is presented in the Appendix.

DISCUSSION

The horizontal separation rates of weighted drogues obtained in this study supply only a lower limit to the actual subsurface diffusion of particles. The position of "particles" such as fish eggs and phyto-

Table III: Rates of separation of drogue pairs for the period up to two hours after deployment

Drogue depth (m)	Mean separation rate m ($m \cdot h^{-1}$)	Standard deviation of m ($m \cdot h^{-1}$)	Intercept c (m)	n
2	8,1	—	4,6	29
10	7,0	1,2	5,1	71
20	7,1	—	3,7	27

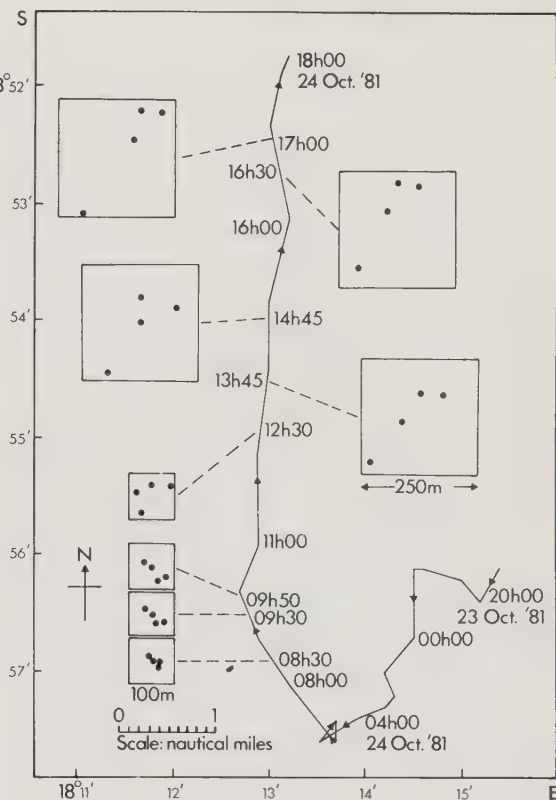


Fig. 3: Transport and separation of an ensemble of identical drogues at 10-m depth (the scales for the main drogue track and for the squares showing separation are different)

plankton in the water column is a function of their density and of the density structure of the water column and, therefore, various degrees of vertical movements are possible. Only when no current shear is present in the vertical plane can drogue separation and particle diffusion be considered analogous. However, at the surface, buoyant particles are limited to movement in the horizontal plane, and they therefore diffuse in essentially the same manner as weighted drogues. Even then drogues would separate more slowly because of their greater size.

The measurements of horizontal separation of the subsurface (i.e. 10 and 20 m) drogues therefore present trends that would be valid for the diffusion of particles in turbulent flows in which current shear in the vertical plane can be ignored. As this was not the case in the present study, further analysis will circumvent the problem by treating horizontal diffusion and horizontal separation as a result of vertical shear separately.

Horizontal diffusion

Csanady (1973) classifies three phases in the horizontal diffusion of a cloud following a point release. Initially, growth in the width of a cloud is proportional to the square root of time, as the eddies containing the most energy are larger than the cloud.

The next phase occurs when diffusion is dominated by eddies of size comparable to the width of the cloud and growth proceeds as $(\text{time})^{1.5}$, or faster than linearly with time. Csanady (1973, p. 94) further states that "... the total duration of this 'explosive' phase of cloud growth is rather short, shorter than the lifetime of the typical 'energy containing' eddy in the field." The data represented in Figure 3 allow an estimate to be made of these scales: an increase in separation of approximately 100 m was effected in 75 minutes or less. This estimate yields an eddy diffusivity coefficient K of $2.2 \times 10^4 \text{ cm}^2 \cdot \text{s}^{-1}$, where $K = UL$ and where U and L are velocity and length scales of $2.2 \text{ cm} \cdot \text{s}^{-1}$ and 100 m respectively.

The third phase occurs when the cloud becomes larger than the size of the eddies containing energy, and growth again proceeds as the square root of time. Figure 3 shows this marked decrease in the separation rate during the afternoon of 24 October.

From Tables II and III it is clear that, during the first 2 hours, the drogue-pair separations at 2, 10 and 20 m are on average very similar linear functions of time. Some individual pair separations did show short (of the order of 30 minutes) phases of rapid growth between periods of slower growth, and this feature is reflected in the high variabilities in separation at a particular time (Table II). The short period of explosive growth measured between 12h30 and 13h45 on 24 October (Fig. 3) remains, however, the only clear example obtained of this phase, because a similar experiment on 25 October did not show such growth during the 6 hours of tracking.

On the basis of the ensemble averages of drogue-pair separation with time up to 2 hours, no dominant phase can be identified. However, aspects of all three phases were noted in the individual separations, but combined they give the linear growth with time found experimentally as the average rate. The estimate of eddy diffusivity that can be obtained from the average "linear" data ($U = 0.19 \text{ cm} \cdot \text{s}^{-1}$, i.e. $7 \text{ m} \cdot \text{h}^{-1}$, and $L = 10 \text{ m}$) is $190 \text{ cm}^2 \cdot \text{s}^{-1}$, which agrees well with other estimates reviewed by Pollard (1977).

Besides investigating the nature of horizontal diffusion, an objective of this study was to estimate the diffusion rate of particles (of drogue size) from the centre of gravity of the particle distribution, and not just relative to each other. This was achieved by

employing the theorem that the mean square separation of two diffusing particles is twice their mean square separation from the centre of gravity.

Sufficient data for this analysis were only available at the 10-m depth, and the differences in separation over the period 20–80 minutes after deployment were calculated. The resulting 12 separations yielded a mean square separation of 84 m^2 , which corresponds to a root-mean-square separation from the centre of gravity of 6.5 m. The standard error of the mean square separation was 26 m^2 . The root-mean-square separation rate of $6.5 \text{ m} \cdot \text{h}^{-1}$ is very similar to the mean separation rate of $7.0 \text{ m} \cdot \text{h}^{-1}$ shown in Table III, in spite of the different methods used to obtain these estimates of "diffusion spread". Hence, it is inferred that the root-mean-square separation rates of the 2-m and 20-m drogues from the centre of gravity can best be estimated by the separation rates presented in Table III, because the latter are based on all of the limited data for these depths.

The estimates of the subsurface diffusion rate must be combined with the separation that would be caused by vertical shear of horizontal velocity before realistic dispersion rates can be obtained. However, the diffusion rate obtained from the 2-m drogues can be regarded as a realistic estimate for floating particles unaffected by wind.

Dispersion as a result of vertical shear of horizontal velocity and diffusion

From the shear speeds presented in Table I, certain deductions can be made to allow operative dispersion rates to be estimated. Firstly, the 2–10 m and 10–20 m shear speeds recorded on half of the 20 tracking occasions add up exactly to the 2–20 m shear speed, implying that the direction of the shear velocity from 10 to 2 m was opposite to that from 10 to 20 m on these occasions. On a further seven occasions, the 2–10 m and 10–20 m shear speeds added up to at least 85 per cent of the 2–20 m speed indicating the same opposing trend. Therefore, the 2–10 m and 10–20 m shear would typically tend to disperse particles above and below the 10-m drogue in opposite directions.

Secondly, the relatively featureless temperature gradient in the upper 30 m (Fig. 2) and the comparable average shear speeds above and below 10 m (Table I) make it reasonable to assume a 2-part linear current profile between 2 and 10 m and between 10 and 20 m as a typical condition. The implications of these assumptions for the separation of particles at slightly different depths, e.g. at 9 and 11 m, can now

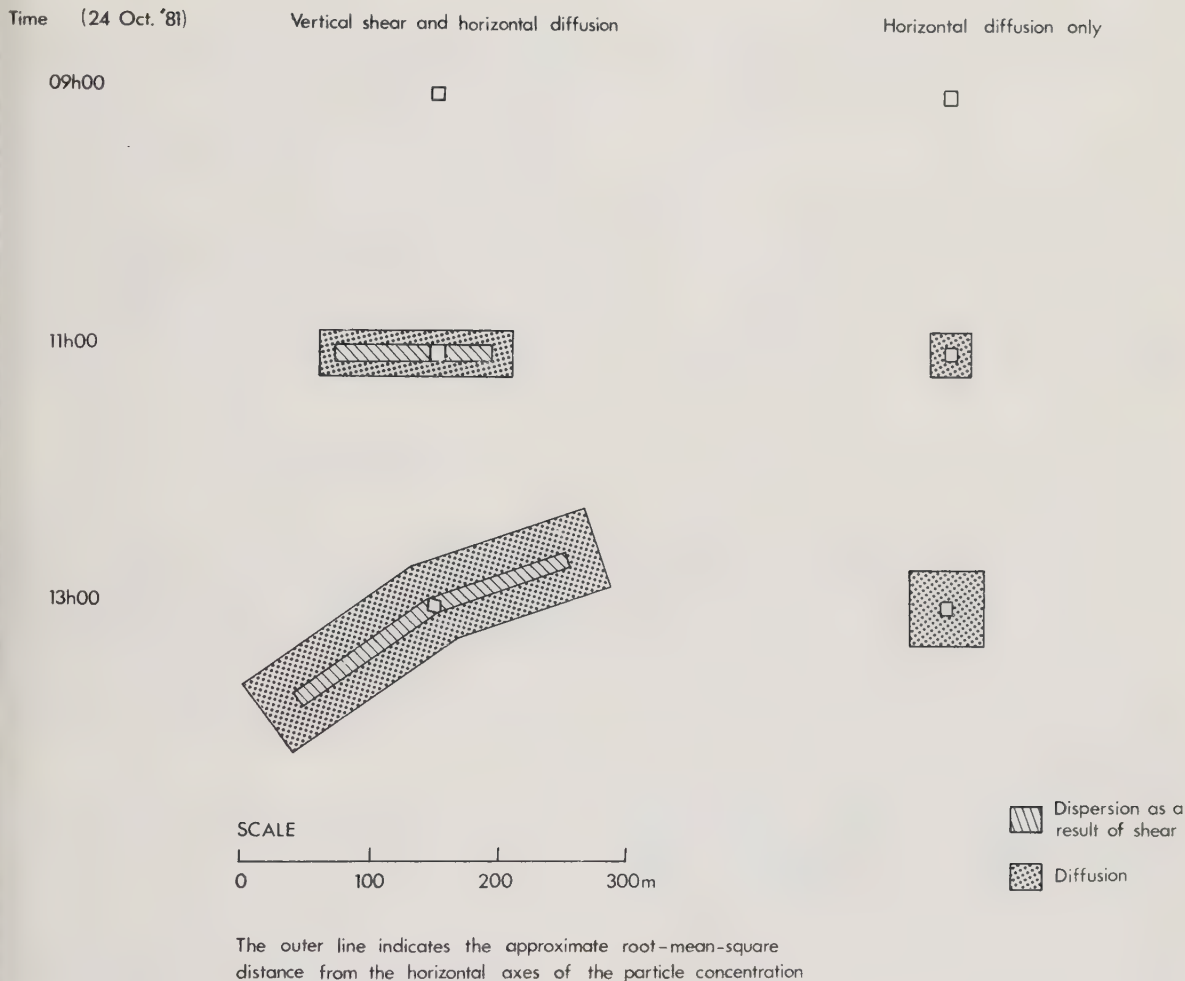


Fig. 4: Plan view of the effects of linear horizontal diffusion and separation caused by vertical shear of horizontal velocity (based on the data given in Table IV)

be examined before considering an aggregation of particles.

Particles at 9 and 11 m would have an average separation speed of $2.1 \text{ cm} \cdot \text{s}^{-1}$ (i.e. one-eighth of the average 2–10 m shear plus one-tenth of the 10–20 m shear) or $76 \text{ m} \cdot \text{h}^{-1}$. This is an order of magnitude greater than the mean horizontal separation rate of $7.0 \text{ m} \cdot \text{h}^{-1}$ for the 10-m drogues. Particles at 8 and 12 m would be separated by 150 m each hour. Therefore, it soon becomes evident that the dominant process causing the dispersion of particles during the

present experiment would have been vertical shear of horizontal velocity.

This shear would tend to separate the particles in a line parallel to the direction of the shear. The “line” of particles would undergo horizontal diffusion which would only be noticeable in a direction normal to the “line” in practice. The real situation soon becomes more complicated, because changes in the velocities at 2, 10 and 20 m (Fig. 2), and in the shear speeds between these depths (Table I), were marked over the minimum 4-hour period separating succes-

Table IV: Real and hypothetical shear velocities for 09h00–13h00 on October 24, 1981

Time	Velocities relative to 10 m			
	2 m		20 m	
	Direction	Speed (cm·s ⁻¹)	Direction	Speed (cm·s ⁻¹)
<i>Actual data</i>				
09h00	275	9	105	6
13h00	205	9	075	9
<i>Hypothetical data</i>				
09h00–11h00	270	9	090	6
11h00–13h00	200	9	060	9

sive measurements. Therefore, the dispersion “lines” would rapidly tend to become curved in the horizontal plane.

A very simple graphic display of horizontal dispersion of particles starting off from a block concentration with horizontal sides of 10 m and depth of 9–11 m is shown in Figure 4. The data used for this Figure were based on those collected on 24 October, but modified slightly as shown in Table IV to show line dispersion and curvature effects separately. Growth of the block as a result of diffusion was considered linear with time.

Figure 4 reflects the combined effect of vertical shear of horizontal velocity and horizontal diffusion of drogue-sized particles. It still presents an underestimate of real dispersion of small particles because of the drogue size and because the model restricts all particles to the depth range 9–11 m, a range which is, in spite of the temperature gradient shown in Figure 2, a conservative condition. Nevertheless, this lower limit of dispersion indicates that physical mixing would rapidly destroy horizontal patchiness of particles that might otherwise occur on a scale of less than a few hundred metres. Furthermore, the rate and extent of particle dispersion will depend largely on the vertical distribution of the patch. Animals able to migrate vertically in the water column could therefore colonize an area at a rate

comparable to the shear speeds over the upper layer.

The small-scale methods employed in this study preclude their use in determining the dynamics of large plankton patches of the order of 5–10 km. However, the current meter and chlorophyll sections normal to the track of the 10-m drogue discussed here may well be able to define scales and processes in this regard. Further work is required to quantify the influence of wind and the thermal structure of the upper layer on both shear and dispersion. The results given in this study were obtained mainly during winds of 10–20 knots and a thermal gradient of 1°C per 10-m depth (Fig. 2) and, therefore, are most applicable to similar environments.

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APPENDIX

As the standard deviation σ of drogue separation l increased linearly with time t (Table II), the least squares regression in which

$$Q = \sum_{i=1}^n (l_i - c - mt_i)^2, \text{ where } m = \text{slope} \text{ and } c = \text{intercept},$$

is minimized, is inappropriate for regressing separation distance on time. A weighting factor is desirable to compensate for the larger standard deviation of l at large t .

Introducing $w_i = (\sigma_i)^{-2}$, minimization of

$$Q = \sum_{i=1}^n w_i (l_i - c - mt_i)^2,$$

(appropriate for maximum likelihood estimation with errors normally distributed with variance σ_i^2) was possible because σ_i values appropriate to particular t_i values were available from Table II. Defining $\bar{l}$ and $\bar{t}$ as

$$\bar{l} = \frac{\sum_{i=1}^n w_i l_i}{\sum_{i=1}^n w_i}$$

$$\bar{t} = \frac{\sum_{i=1}^n w_i t_i}{\sum_{i=1}^n w_i},$$

the mean drogue separation rate is given by

$$m = \frac{\sum_{i=1}^n w_i (t_i - \bar{t})(l_i - \bar{l})}{\sum_{i=1}^n w_i (t_i - \bar{t})^2}.$$

The standard error of m is given by

$$\text{Standard error } (m) = \left[\sum_{i=1}^n w_i (t_i - \bar{t})^2 \right]^{-1/2} \dots (1)$$

and the intercept by

$$c = \bar{l} - m\bar{t}.$$

For the 2 and the 20 m drogues insufficient points were available at each t_i in order to obtain a reliable estimate of σ_i . However, because σ_i was linearly correlated with t_i for 10 m depth (Table II), t_i was used as a weighting factor instead of σ_i . This precludes the use of (1) to calculate the standard error of m in these cases, though.

INVESTIGATIONS INTO METHODS OF DETERMINING ORGANIC POLLUTION IN SEAWATER. 3. THE USE OF ULTRA-VIOLET SPECTROPHOTOMETRY

P. CHAPMAN

The ultra-violet absorption of seawater samples from Saldanha Bay and Langebaan Lagoon has been measured on four surveys of the area. Measurements were made at 230 nm and by integrating between 250 and 350 nm. When the results were compared with values of oxygen absorbed (OA) for the same area, it was found that there was a good correlation between the two parameters except during the winter storm season. The suitability of ultra-violet absorption as a means of measuring the pollution from fish factories is discussed.

Die ultraviolet-absorpsie van seewatermonsters van Saldanhabaai en die Langebaan-strandmeer is gemeet tydens vier opnames van die gebied. Metings is by 230 nm gedoen en, deur integrasie, tussen 250 en 350 nm. Toe die resultate met waardes van suurstof geabsorbeer (OA) vir dieselfde gebied vergelyk is, was die bevinding dat daar 'n goeie korrelasie tussen die twee parameters is, behalwe tydens die stormseisoen in die winter. In hoe 'n mate ultraviolet-absorpsie geskik is vir die meet van besoedeling deur visfabrieke, word bespreek.

Previous studies (Chapman 1980a, b) have considered tests of chemical oxygen demand (COD) and oxygen absorbed (OA) for determining the organic pollution of seawater. The first is known to be affected by the chloride content of the sample, the chloride requiring large quantities of mercury to complex it, thus creating problems of effluent disposal. OA measurements, however, suffer from the drawback of affecting different groups of compounds in different ways, and it is therefore difficult to compare results from different areas if the effluent make-up is not the same. In South Africa, however, this drawback may not be such a problem because the two most commonly encountered organic effluents are sewage and fish-factory wastes.

Several authors have attempted to overcome these problems by the use of ultra-violet (UV) spectrophotometry. Ogura (1965) and Ogura and Hanya (1968) showed that, in seawater around Japan, there was a relationship between the absorbance at 220 nm and both COD and transparency measurements, but that it was not readily quantifiable. Foster (1973) and Foster and Morris (1971, 1974a, b) also used spectrophotometry to determine sites of organic input to the sea, using the deviations from a plot of absorbance on salinity to show "dirty" areas. Mattson *et al.* (1974) measured the absorbance of seawater at 254 nm on a cruise through the Florida Keys and found it was closely related to the total organic carbon content. Sheppard (1977) has, however, since investigated the UV absorption characteristics of samples from the Tyne estuary, where he found that estimates of pollution caused by sewage addition could only be made when wavelengths longer than 260 nm were used. The high levels of peat in this area were considered to affect his results.

The UV absorbance of most seawater samples

resembles that shown in Figure 1. In oceanic waters, the absorbance at 350 nm is negligible, although it increases in coastal waters where there is generally more turbidity (Foster and Morris 1974a). As the absorbance wavelength decreases, the absorbance increases to a maximum in the 200–220 nm region. This has been attributed to absorption by organic matter, nitrate and bromide (Armstrong and Boalch 1961; Ogura and Hanya 1966, 1967). In most surface waters, where nitrate is depleted and bromide is virtually constant, or at wavelengths greater than 230 nm (Ogura and Hanya 1966), the absorption resulting from the presence of these ions may be ignored. Any changes in absorption are therefore solely caused by changes in the organic concentration within the sample.

The use of UV absorbance measurements to estimate organic pollution has the advantages of being simple, quick, and requiring no chemical back-up facilities. This study was undertaken to compare determinations of OA with spectrophotometric measurements. By this means it was hoped to establish a simple, general method for the determination of pollution, which would be rapid and of widespread applicability.

SAMPLING

Samples were taken within Saldanha Bay, including Langebaan Lagoon (Fig. 2). The port of Saldanha is important as an ore exporting terminal, as well as being a major landing harbour for the pelagic, demersal (whitefish) and rock-lobster fisheries. This part of the South African coast is also known for its high productivity, values of carbon

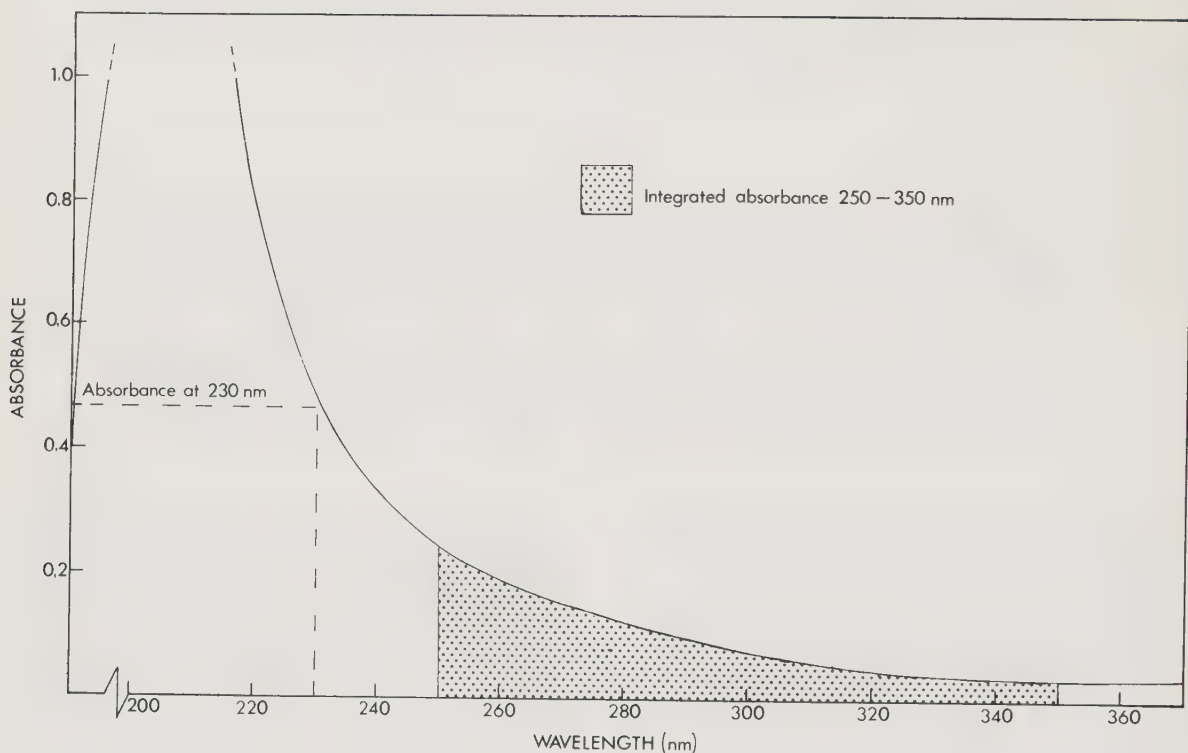


Fig. 1: Ultra-violet absorption characteristics of a seawater sample from Saldanha Bay

production of up to $2\,500\text{ mg}\cdot\text{m}^{-2}\cdot\text{day}^{-1}$ being reported by Henry *et al.* (1977).

The samples were obtained during routine monitoring cruises in December 1977 and March, June and September 1978. Where the water depth allowed, samples were taken by means of an N.I.O. bottle from 0, 5, 10, 20 and 30 m, together with a sample from just above the bottom at intermediate depths. The samples were not filtered, because in this area the organic pollution is caused both by water containing blood and other dissolved material and by fish particles. The samples were kept frozen at -20°C in acid-washed polythene bottles before analysis — this treatment has not been shown to affect the results, although it is possible that rupture of some phytoplankton cells may have occurred.

METHODS

OA analyses were performed by the method of the South African Department of Water Affairs (1969)

utilizing an acidic digestion with permanganate as outlined by Chapman (1980b). Spectrophotometric observations were made using 5-cm silica cells on a Varian Techtron 635 UV-Vis double-beam spectrophotometer connected to a Corning 840 flat-bed recorder. A scale setting of 0 - 1 absorbance units was used. Measurements were made against glass-double-distilled water. The absorbance was scanned between 230 and 350 nm, after zeroing the instrument with glass-double-distilled water in both cells. Integrated absorbances were obtained by counting the number of blocks ($2 \times 2.5\text{ mm}$) between the absorbance curve and the baseline in the range 250-350 nm. The absorbance at 230 nm was also noted. A solution of phenol in distilled water ($1.595 \times 10^{-4}\text{ M}$) gave an integrated absorbance, calculated in the same manner, of $1\,300 \pm 20$ blocks.

RESULTS AND DISCUSSION

The results from the December 1977 survey are

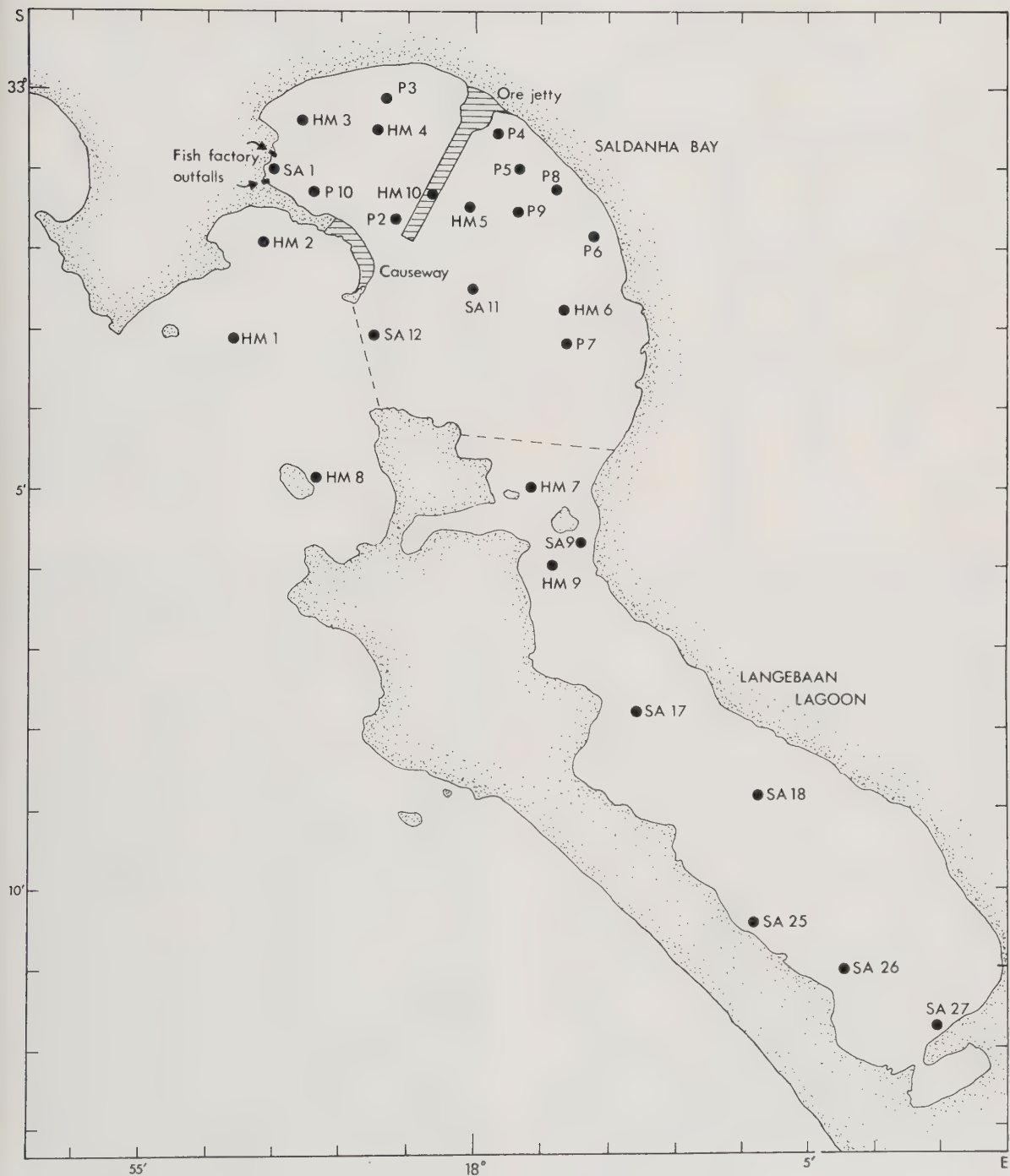


Fig. 2 Station positions for all samples taken during the four surveys (not all stations were sampled on each survey)

Table I: UV absorbance measurements and oxygen absorbed (OA) values for samples from Saldanha Bay, December 1977

Station	Depth (m)	OA (mg ℓ ⁻¹)	Absorbance at 230 nm	Integrated absorbance 250 — 350 nm
SA 1	0	3,10	0,484	2 133
	5	1,80	0,250	1 033
SA 9	0	1,40	0,295	1 094
	5	1,40	0,330	1 268
SA 11	9	1,40	0,130	808
	0	2,29	0,290	1 436
	5	2,61	0,375	1 765
	10	1,40	0,205	539
	17	1,40	0,206	1 456
SA 12	0	1,80	0,310	1 365
	5	1,84	0,310	1 185
	10	1,72	0,230	858
	20	2,37	0,480	693
SA 17	0	1,64	0,235	782
	5	1,44	0,295	915
SA 18	0	1,32	0,255	943
SA 25	0	1,36	0,330	1 015
	5	1,44	0,290	971
SA 26	0	1,56	0,340	1 155
SA 27	0	1,84	0,550	2 255
HM 1	0	1,98	0,270	1 128
	5	1,78	0,200	695
	10	1,78	0,275	992
	20	2,22	0,250	873
	30	1,58	0,230	587
	38	1,90	0,270	618
HM 2	0	1,96	0,345	1 458
	10	1,76	0,270	884
	19	1,80	0,195	621
HM 5	0	3,75	0,560	2 696
	5	3,33	0,435	2 168
	10	1,35	0,180	576
HM 7	0	1,80	0,225	640
	5	1,32	0,225	644
	9	1,72	0,215	653
HM 8	0	1,46	0,180	526
	5	1,39	0,195	595
	10	1,54	0,210	553
	14	1,07	0,290	1 133
HM 9	0	1,24	0,295	616
	5	1,44	0,260	753
HM 10	0	3,75	0,390	1 897
	5	2,69	0,360	1 643
	10	1,39	0,195	574
	20	1,54	0,180	419
	30	1,54	0,220	1 216

shown in Table I. Results from the other surveys are not listed herein, but were of similar magnitude and are obtainable from the author. During this period the whitefish factory was operative, but not the pelagic fish processing plant. Pelagic operations commence on January 1 and continue until the quotas have been filled, sometimes as late as May or June. It is noticeable that, for stations showing high OA or absorbance values, the highest values were found at the surface, and there was a decrease down the water column. There are two main reasons for this observation. Firstly, the effluent from the fish processing factories commonly contains 500 ppm (w/v) and may contain up to 1 000 ppm fish oil, together with blood and wash water, depending on what fish is being processed and the effectiveness of the polishing process in the factory (figures supplied by Department of Water Affairs). Any oil would therefore tend to stay on the surface. There is also a strong thermocline in the inner Bay which tends to prevent mixing throughout the water column — this is demonstrated by the nutrient analyses of samples taken at the same stations, e.g. SA 11 where the nitrate values for 0, 5, 10 and 17 m are 0,5, 0,5, 14,6 and 20,0 μM respectively, and the temperatures at the same depths are 17,8, 17,0, 13,6 and 11,8°C.

In the case of the December results given in Table I, it is considered that the presence of the thermocline was the more important factor, because the effluent from processing whitefish contains virtually no oil. When the pelagic fishery is operative, however, the oil concentration in calm conditions may be high enough to form slicks of oil close to the outfall.

Although Ogura and Hanya (1966) showed that nitrate has some effect on the absorbance of seawater below 230 nm (a 40 μM solution producing an absorbance of about 0,15 per centimetre of path-length at 220 nm), this ion exhibits negligible absorption above 230 nm. The salinity in Saldanha Bay remains constant at about 34,9‰ (Shannon and Stander 1977) although, at the southern end of Langebaan Lagoon, salinities may rise to over 37‰ during the summer. In the December 1977 survey, results from the Bay were in the range 34,82–34,92‰ while in the Lagoon the maximum value recorded was 27,98‰ at station SA 27 (Fig. 2). These higher salinities in the Lagoon are the result of the high degree of evaporation that takes place over this very shallow water body. It was therefore considered that bromide would exert a virtually constant effect, which is anyway probably negligible above 250 nm, and that variations in UV absorption could be considered as depending solely on variations in organic content.

One major question that could be posed is whether the absorption shown by these samples was caused by pollution from the fish factories or by organic

Table II: Relationships between OA measurements, integrated absorbance between 250 and 350 nm and absorbance at 230 nm for water samples from Saldanha Bay, 1977 — 1978

Survey	Relationship between OA and							
	Absorbance at 230 nm				Integrated absorbance 250 - 350 nm			
	Regression	<i>r</i>	<i>n</i>	<i>l</i>	Regression	<i>r</i>	<i>n</i>	<i>l</i>
<i>All stations</i>								
Dec. 1977	OA = 4,27Abs + 0,60	0,666*	47	±1,43	OA = 0,00086Abs + 0,93	0,743*	47	±2,32 × 10 ⁻⁴
Mar. 1978	OA = 10,78Abs - 1,62	0,802*	56	±2,19	OA = 0,00175Abs - 0,25	0,681*	55	±4,16 × 10 ⁻⁴
Jun. 1978	OA = 10,29Abs - 0,20	0,547*	47	±4,73	OA = 0,00124Abs + 1,20	0,632*	44	±4,73 × 10 ⁻⁴
Sep. 1978	OA = -2,48Abs + 4,47	-0,066	55	—	OA = -0,00097 Abs + 4,50	0,112	55	—
<i>Inner Bay and Harbour</i>								
Dec. 1977	OA = 5,92Abs + 0,29	0,846*	19	±1,89	OA = 0,00108Abs + 0,76	0,840*	19	±3,52 × 10 ⁻⁴
Mar. 1978	OA = 11,82Abs - 1,98	0,822*	36	±2,84	OA = 0,00149Abs + 0,08	0,638*	35	±5,60 × 10 ⁻⁴
Jun. 1978	OA = 9,87Abs + 0,16	0,525*	28	±6,43	OA = 0,00117Abs + 1,36	0,558*	25	±7,46 × 10 ⁻⁴
Sep. 1978	OA = 0,027Abs + 3,63	0,003	36	—	OA = -0,00191Abs + 4,70	-0,252	36	—

* Significant at 1-per-cent level

— Not computed

r = Regression coefficient*n* = Number of samples*l* = 95-per-cent confidence limit of slope

material excreted by natural phytoplankton populations, the so-called Gelbstoffe (Kalle 1962, 1966). From Table I, it might be thought that the latter was the cause, because the absorbance of surface samples was higher than that for samples taken below 5 m. However, a comparison of results for stations inside and outside the inner Bay excluding the Lagoon (Fig. 2) shows that the highest values came from stations inside the inner Bay (SA 1, SA 11, SA 12, HM 5, HM 10). Because production values have been shown to be similar throughout Saldanha Bay (though not the Lagoon — Henry *et al.* 1977), it would seem that there is an increased organic loading in the inner Bay presumably resulting from pollution. OA and UV absorbance values from below 5 m in the inner Bay fell in the same range as surface and bottom values from outside the area. Plots of OA values against either absorbance at 230 nm or the integrated absorbance between 250 and 350 nm showed little difference depending on whether all samples, or merely those from the inner Bay, were considered. This is shown in Figures 3 and 4, where the regression lines corresponding to the equations in Table II have been plotted.

Table II shows that the relationships between OA and the absorbance at 230 nm and between OA and the integrated absorbance at 250 — 350 nm were highly significant for most of the year. It can therefore be inferred that, during the period December — June (which incorporates the pelagic fishing season at Saldanha), the major contributor to the absorbance of seawater samples in Saldanha Bay is organic matter. Samples from the March survey

showed the highest absorbances during the year (Figs. 3 and 4), which would be expected because biological production was high and the effluent input from the fish factories was maximal at this time.

From the slopes of regression lines shown in Figures 3 and 4 (Table II), it may be seen that the relationships between OA and absorbance at 230 nm and between OA and integrated absorbance do not remain constant over the year. This is the result of changes in the composition of the organic matter contributing to the three parameters. Whereas the OA value is dependent solely on the easily degradable portion of the organic matter in the area, absorbance values include contributions from both pollutants and naturally occurring material, much of which may not be easily degraded. These organic constituents will certainly vary during the year, depending on the output from the fishing factories (both as regards quantity and the species composition of the catch), phytoplankton production and resuspension of settled material. The last two factors are not expected to vary much during the generally settled conditions that are found in the Bay during the summer, and it would be expected that the nature of the effluent from the factories would have the most impact. For example, whitefish has a different biochemical composition from that of anchovy, therefore producing a different effluent.

The different compounds in each effluent will have different extinction coefficients and will show the strongest absorbance at different wavelengths, e.g. the extinction coefficients of conjugated dienes may be as high as 10 000—20 000, whereas for substituted

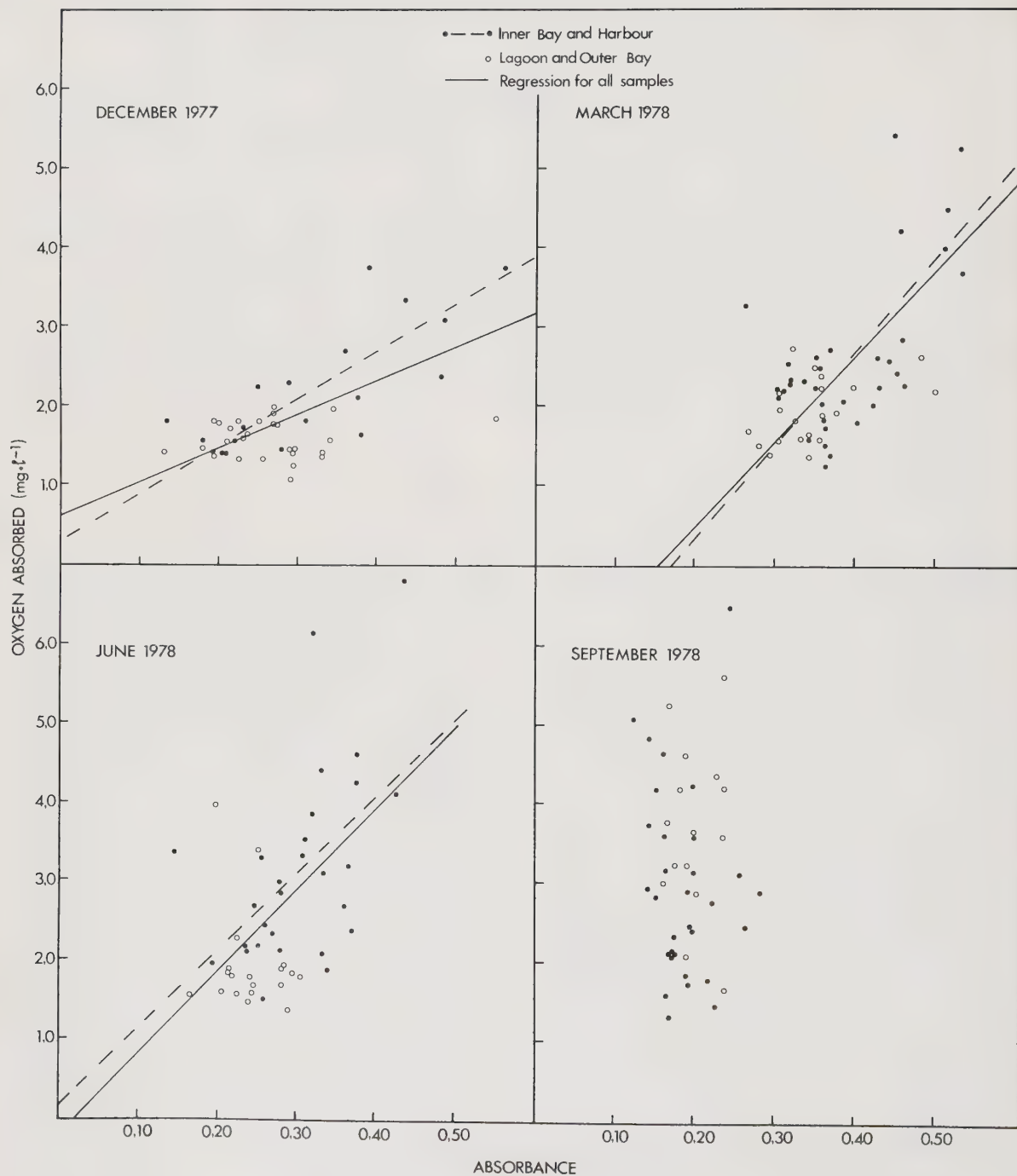


Fig. 3: Relationships between the OA of each sample and the ultra-violet absorption at 230 nm

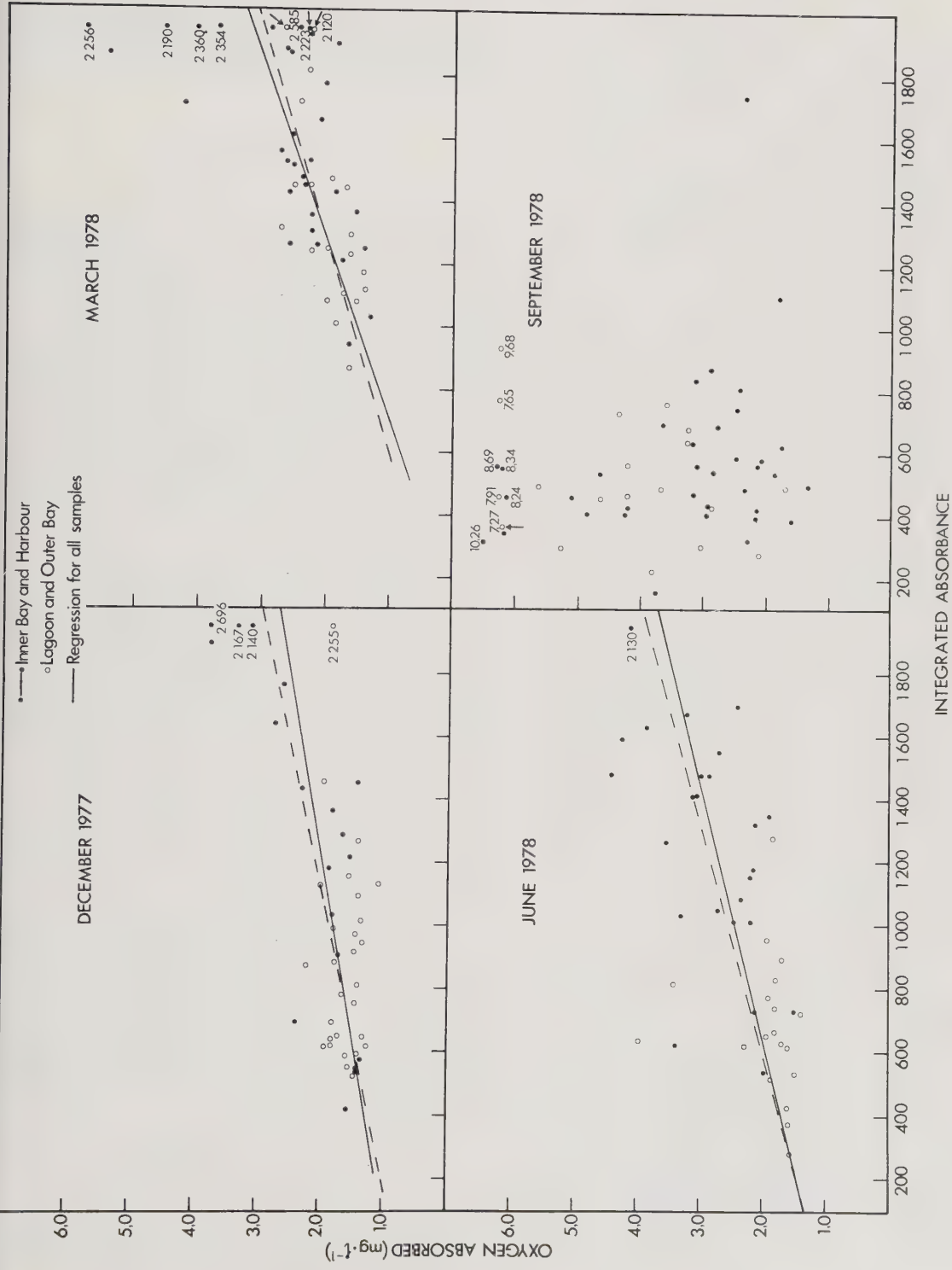


Fig. 4: Relationships between the OA of each sample and the integrated absorbance between 250 and 350 nm

benzenes they are about an order of magnitude less (Williams and Fleming 1966). The spread of the data points lends evidence to this assumption. In Table II, values for the 95-per-cent confidence limits of the slope are given for the three surveys where significant relationships between the parameters were found.

There is a marked difference between the spread of data points for the December and March surveys, but the difference was less marked for the June survey, as shown by both the large confidence limits and the smaller regression coefficient. By June, most of the pelagic-fish quotas had been filled, though the whitefish company was still operating.

It should not be expected that the agreement between OA and absorbance would be much better than shown, because the OA values are not a direct measurement of the organic carbon content, but merely an indicator of easily oxidizable matter (Chapman 1980b). The highest absorbances were almost always associated with samples from the inner area of the Bay, especially the area between the ore jetty and the causeway (Figs. 3 and 4). The differences between this area and the outer Bay and Lagoon, and the reasons for such differences, are discussed more fully by Chapman and Moldan (in preparation), but they depend to a large extent on the decreased circulation in the inner Bay following the construction of the causeway.

The data from the September 1978 survey, however, vary considerably from those of the other three seasons sampled. This variation is probably caused by a combination of decreased organic input (as shown by the scatter of the points from the inner Bay) and increased turbidity of the water column. During winter the thermocline in the Bay tends to disappear, and the water becomes well mixed (Shannon and Stander 1977). The effect of the predominantly westerly wind and wave action is then to increase the amount of material in suspension in the water column, so that both turbidity (as measured by UV absorbance) and the OA values become more variable. The breakdown in the relationship between OA and UV absorbance is clear from the correlation coefficients for all stations given in Table II (0.112 for the integrated absorbance between 250 and 350 nm and -0.066 for the absorbance at 230 nm).

Saldanha Bay might perhaps be thought a special case in that there are no significant freshwater inputs which could cause an increase in the UV absorbance of the water. However, all the major fish-processing factories in South Africa are situated south of Lambert's Bay on the West Coast. Because there is very little freshwater input along this coastline during the summer months when production is at its highest, it would appear from their good agreement that OA

values (which up to now have been accepted as giving a reasonable measure of pollution) and UV absorbance can equally be used to monitor pollution from these sources.

CONCLUSIONS

The results of these surveys show that it is possible to use the UV absorbance of water samples either by measurement at 230 nm or integration between 250 and 350 nm as a measure of the organic pollution in the water, although the method is subject to some constraints. Firstly, there should be no freshwater inputs to the system in the neighbourhood of the pollutant source, because these would tend to swamp the contribution from the effluent (Sheppard 1977). Secondly, there should be little change in salinity in the area, because of the absorbance by bromide. Also, there should preferably be little variation in nitrate because of the effect of this ion below 230 nm, though above 250 nm such interference can probably be ignored.

Probably the most important constraint with regard to this method of measurement is that the organic carbon content of the water is not being measured directly. This applies also to the use of OA measurements and, to a lesser extent, to COD values. As a result, samples from different areas cannot generally be compared, as has been demonstrated for freshwater samples by Stewart and Wetzel (1981). In this respect it would seem that, for monitoring fish factory effluent, UV absorption is ideally suited — there is little freshwater input along the west coast of South Africa, the salinity is virtually constant, and the effluent characteristics (although varying with the species of fish being processed) also remain similar throughout the area.

Care is still needed, however, because of the change in absorption characteristics of the area between summer and winter. It is possible that the use of a turbidity correction, e.g. measuring the absorbance at 546 nm where organic matter is considered not to interfere (Mattson *et al.* 1974), would have compensated partly for the increased absorbance resulting from suspension of bottom particles found in September. This was not, however, investigated during this study.

ACKNOWLEDGEMENTS

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A NOTE ON THE EFFECT OF BOTTLE SIZE ON PHYTOPLANKTON PRODUCTION MEASUREMENTS

P.C. BROWN

Nineteen experiments were conducted to investigate the effect that size of the incubation bottle has on the measurement of phytoplankton production in the coastal waters of the Cape Peninsula. No significant differences were found amongst production estimates made with 125-mℓ, 250-mℓ, 500-mℓ or 1 000 mℓ bottles. However, for no apparent reason, the 60-mℓ bottle gave estimates significantly lower than the other bottles. Zooplankton densities were established for each experiment, and the effects of including zooplankton in incubation bottles is discussed. It was finally decided to use 125-mℓ bottles for routine incubations, firstly because handling was easier, and secondly to minimize the chances of inadvertently including zooplankton.

Die effek van inkubasiebottelgrootte op die bepaling van fitoplanktonproduksie in die kuswaters van die Kaapse Skiereiland is eksperimenteel ondersoek. Negentien eksperimente is uitgevoer en geen beduidende verskille kon gevind word tussen produksiewaardes verkry deur middel van 125-mℓ, 250-mℓ, 500-mℓ- en 1 000-mℓ-bottels nie. Produksiewaardes verkry van 60-mℓ-bottels was egter om onverklaarbare redes beduidend laer as vir bottels van die ander groottes. Soöplanktondigtheid is vir elke eksperiment bepaal en die gevolge van die aanwesigheid van soöplankton in die inkubasiebottels word bespreek. Daar is uiteindelik besluit om 125-mℓ-bottels vir roetine-inkubasies te gebruik, eerstens omdat dit geriefliker hanteer en tweedens om die moontlikheid van toevallige insluiting van soöplankton by die monsters tot die minimum te beperk.

In the open ocean a dynamic equilibrium is maintained between phytoplankton production and zooplankton grazing. If the grazing effect is removed, primary production can be measured by isolating a volume of water and subjecting it to conditions (light, temperature, agitation, etc.) similar to those from where it was taken (Sheldon *et al.* 1973). Although such a state of dynamic equilibrium is seldom found in the highly productive but physically unstable upwelling area off the Cape Peninsula, the grazing effect of zooplankton should ideally be removed for measurements of primary production.

Sutcliffe *et al.* (1970) used a screen to remove particles greater than 200 μm , assuming these to be zooplankters, but they found that the phytoplankton that passed through the screen sometimes grew and at other times it did not. Evidently, phytoplankton cells and chains could be damaged or even retained by the mesh and, moreover, small zooplankters could pass through it.

Sheldon *et al.* (1973) suggested that, instead of screening, a small volume of water should be isolated, because the probability of including a zooplankter in a small sample is less than if a large volume of water is used. They found that the rate of particle production (measured by means of a Coulter Counter) increased rapidly with decrease in the size of the incubation bottle. This increase was attributed to the elimination of grazers rather than to increased bacterial production, because growth took place at a relatively large particle size. The choice of bottle size might

therefore depend on zooplankton density.

Bottles used by different researchers to measure phytoplankton production vary in volume between about 25 and 300 mℓ. The effect of bottle size on production estimates was investigated in the coastal waters of the southern Benguela region on 19 occasions. A total of 15 experiments was made approximately 2 km off Oudekraal (33°59'S 18°20,6'E) and 4 the same distance north of Robben Island (33°46,4'S 18°22,3'E). Phytoplankton biomass was estimated from chlorophyll *a* concentrations, measured according to the spectrophotometric method of the SCOR/UNESCO Working Group 17 (1966). The oxygen method (modified from Strickland 1960) was employed to measure production.

Water drawn from the sea surface by means of either a plastic bucket or an N.I.O. bottle was mixed in a large container. Subsamples were siphoned into two light and two dark 1000-mℓ, 500-mℓ, 250-mℓ, 125-mℓ and 60-mℓ incubation bottles. An initial bottle was drawn before and after each set of incubation bottles was filled, and the oxygen was fixed immediately.

Zooplankton densities were established by pumping either 200 or 500ℓ of water from just below the surface by means of a pump with an inlet diameter of 7,6 cm, and cascading the water through 200- μm and 37- μm mesh nets. Both fractions were retained for the identification and enumeration of zooplankton.

Phytoplankton biomass ranged from 0 to 20 mg chl *a* · m⁻³. In only 10 of the 19 experiments (Table I) were gross production measurements within

Table I: Estimates of phytoplankton gross production in five different sizes of incubation bottle — the range (in brackets) is calculated from replicate light (L) and dark (D) bottles, the lower estimate from the low L and high D oxygen concentrations and the upper estimate from the high L and low D concentrations

Expt	Date	Station†	Biomass (mg chl <i>a</i> m ⁻³)	Estimate of gross production (mg C m ⁻³ h ⁻¹) for various bottle sizes				
				1 000 ml	500 ml	250 ml	125 ml	60 ml
3	15/11/77	O	1,3	19,7 (15,6-23,8)	21,6 (20,1-23,1)	22,3 (10,4-34,2)	17,1 (11,2-23,1)	10,7 (7,4-14,1)
4	17/11/77	O	9,1	50,9 (45,8-55,9)	57,1 (53,6-60,6)	59,0 (48,9-69,1)	52,8 (48,9-56,7)	41,1 (36,5-45,8)
5	6/12/77	O	24,1	212,7 (206,2-219,2)	217,6 (186,5-248,7)	225,8 (219,2-232,3)	195,1 (196,3-209,5)	106,4 (81,8-130,9)
8	2/2/78	O	2,4	49,9 (43,2-56,6)	46,9 (43,2-50,6)	43,2 (41,7-44,7)	48,4 (46,2-50,6)	36,5 (34,2-38,7)
9	6/2/78	O	1,5	25,7 (23,4-27,9)	26,2 (22,3-30,2)	24,6 (23,4-25,7)	23,4 (22,3-24,6)	24,0 (21,2-26,8)
10	15/2/78	O	7,7	122,1 (114,3-129,8)	125,1 (122,7-127,4)	126,2 (123,9-128,6)	134,0 (132,2-135,8)	113,8 (109,6-117,9)
11	22/3/78	O	7,2	65,4 (62,3-68,6)	53,0 (16,6*-89,3)	61,8 (49,9-73,7)	63,4 (56,1-70,6)	101,8 (86,2-117,4)
12	25/4/78	RI	1,5	20,3 (16,5-24,0)	17,2 (17,2-17,2)	16,1 (13,7-18,6)	13,7 (9,6-17,9)	19,2 (18,6-19,8)
13	12/7/78	O	3,1	24,3 (20,8-27,8)	33,2 (29,8-36,7)	30,3 (23,8-36,7)	26,3 (25,8-26,8)	18,8 (14,9-22,8)
19	12/3/79	RI	8,4	88,8 (86,0-91,6)	82,6 (73,7-91,6)	97,2 (83,7-110,6)	87,1 (81,0-88,2)	82,1 (74,8-89,3)

†O = Oudekraal, RI = Robben Island

* One zooplankton in light bottle reduced gross production by ~ 80 per cent (see text)

the limits of precision of the oxygen method. Of these, no significant differences (Wilcoxon signed-ranks test, Dixon 1977) in gross production were found among the 1 000-ml, 500-ml, 250-ml and 125-ml incubation bottles (Table II). This agrees with findings published by UNESCO (1973). However, gross production in the 60-ml bottles was significantly lower ($p < 0,05$) than in the other bottle sizes. The rate of production did not increase with decrease in bottle size as was found by Sheldon *et al.* (1973).

Zooplankton species and numbers are listed in Table III. Most of the species are either herbivorous or omnivorous (Lazarus 1975). Zooplankton densities ranged between 0 and 6,4 animals per litre, though large numbers of very small copepod nauplii (retained by the 37- μ m mesh net) were not included in the density estimates. Zooplankton densities off the Cape Peninsula were estimated independently by Hutchings (1979) at between 0,2 and 3,5 animals per litre from WP-2 net (200- μ m mesh) samples collected in midsummer 1969, but his estimates are lower probably because only a 200- μ m mesh net was used. At the maximum density encountered (6,4 animals per litre in Experiment 19), the chance of a zooplankton occurring in a 1 000-ml incubation bottle is high, though oxygen levels gave no indication of the presence of zooplankton in the incubation bottles.

In Experiment 11, a copepod was found in one of the two 500-ml light bottles, and gross production in this bottle was 80 per cent less than in the one which contained no copepod (Table I). This finding supports the suggestion that the presence of zooplankton in an incubation bottle can, by respiration and grazing, cause an underestimate of primary production. No marked differences in gross production between the duplicate light bottles were observed in other cases, despite the fact that zooplankton densities were higher in Experiments 12 and 19 (Table II). This may have been because of the difference in

Table II: A comparison of gross production as measured in five different sized incubation bottles by means of the Wilcoxon signed-ranks test

Bottle size	1 000 ml	500 ml	250 ml	125 ml	60 ml
1 000 ml					
500 ml	NS				
250 ml	NS	NS			
125 ml	NS	NS	NS		
60 ml	*	*	*	*	

* $p \leq 0,05$

NS = not significant

Table III: Zooplankton species, numbers and densities in surface waters

Experiment	Species	Number	Total	Volume filtered (ℓ)	Animals per litre
3	<i>Centropages brachiatus</i>	2	2	500	0,0
4	<i>Oithona</i> sp. <i>Paracalanus parvus</i> <i>P. crassirostris</i> (Copepod nauplii)	9 4 1 (20)	14	200	0,1
5	<i>C. brachiatus</i> <i>Oithona</i> sp. <i>P. crassirostris</i> (Copepod nauplii)	94 5 1 (20)	100	200	0,5
8	<i>Oithona</i> sp. <i>P. parvus</i> <i>Oncaea</i> sp. Calanid juveniles (Copepod nauplii)	271 3 1 5 (809)	280	200	1,4
9	<i>C. brachiatus</i> <i>Oithona</i> sp. <i>P. parvus</i> <i>Oncaea</i> sp. <i>Ctenocalanus</i> sp. <i>Clausocalanus</i> sp. <i>Microsetella rosea</i> Calanid juveniles Unrecognizable (Copepod nauplii)	135 132 30 9 4 30 3 153 167 (2 660)	663	200	3,3
10	No counts				
11	<i>C. brachiatus</i> <i>Oithona</i> sp. <i>P. parvus</i> <i>P. crassirostris</i> <i>Paracartia africana</i> Calanid juveniles Unrecognizable (Copepod nauplii)	31 65 19 1 1 11 8 (451)	136	200	0,7
12	<i>C. brachiatus</i> <i>Oithona</i> sp. <i>P. parvus</i> <i>P. crassirostris</i> <i>Calanoides carinatus</i> <i>Clausocalanus</i> sp. <i>Oncaea</i> sp. Calanid juveniles Unrecognizable (Copepod nauplii)	118 517 104 6 13 1 1 60 1 (1 811)	821	200	4,1
13	No counts				
19	<i>C. brachiatus</i> <i>Oithona</i> sp. <i>P. parvus</i> <i>P. crassirostris</i> <i>Clausocalanus</i> sp. <i>Nannocalanus minor</i> <i>Paracartia africana</i> Calanid juveniles Unrecognizable (Copepod nauplii)	730 195 148 18 9 8 75 27 72 (43)	1 282	200	6,4

sampling methods employed for zooplankton and for the water for measurements of primary production. Zooplankton probably has less chance of avoiding the end of a pipe drawing water at a rate of $100\ell \cdot \text{min}^{-1}$, than they would a bucket or an N.I.O. bottle. Consequently, zooplankton densities as estimated by the pump are probably greater than those that would be obtained by sampling with a bucket or an N.I.O. bottle. With the last two samplers, a large proportion of the zooplankton could easily be excluded.

Even though there are no significant differences in production estimates in the 1000-m ℓ , 500-m ℓ , 250-m ℓ and 125-m ℓ bottles, it is expedient to use the smallest bottle for ease of handling and because the smaller the volume of water used, the less likely it is that a zooplankton would be included in the bottle. The relatively lower estimate of gross production in the 60-m ℓ bottle appears to be unrelated to the presence of zooplankton and remains unexplained.

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PATTERNS OF CARBON ASSIMILATION IN PHYTOPLANKTON FROM THE SOUTHERN OCEAN

R.G. BARLOW AND J.L. HENRY

Assimilation of ^{14}C -bicarbonate into the end-products of photosynthesis was measured at five stations in the Southern Ocean. At stations where temperatures were below 0°C , the rate of synthesis of lipid, polysaccharide and protein appeared to be slow, because most of the label was detected in the low-molecular-weight metabolites. At stations where temperatures were $0-2^{\circ}\text{C}$, most of the assimilated carbon was detected in the protein fraction, at the expense of its incorporation into lipid and polysaccharide. These two patterns of photosynthesis were observed at light intensities of 100, 40 and 8 per cent of the surface light intensity.

Die opneem van ^{14}C -bikarbonaat in die eindprodukte van fotosintese is by vyf stasies in die Suidelike Oseaan gemeet. By stasies waar temperature benede 0°C was, was die sintesetempo van lipied, polisakkaried en proteien blykbaar stadig, omdat die grootste gedeelte van die spoorder in die metaboliete van lae molekulêre gewig bemerk is. By stasies waar temperature $0-2^{\circ}\text{C}$ was, is die meeste van die geassimileerde koolstof in die proteïenfraksie bemerk, ten koste van opneming in lipied en polisakkaried. Hierdie twee patrone van fotosintese is by ligintensiteite van 100, 40 en 8 persent van die oppervlakligintensiteit waargeneem.

The physiological state of marine algae may be determined by measuring the pattern of carbon-14 incorporation into major end-products of photosynthesis. Investigations of this nature have been undertaken on natural populations in Narragansett Bay (Hitchcock 1978), in the Gulf of Maine (Morris and Skea 1978), in the Caribbean Sea (Li *et al.* 1980) and in the southern Benguela Current (Barlow 1982a,b). Variations in light intensity, nutrient availability and temperature were found to have an effect on the distribution of carbon-14 between various biochemical components.

During the First International Biomass Experiment in the Southern Ocean during 1981, one of the authors (J.L.H.) was engaged in measurements of primary production. At certain stations, extra water samples were incubated with radioactive carbon for the purpose of examining the assimilation of carbon into various end-products of photosynthesis in phytoplankton from waters in the vicinity of Antarctica. The results of the study are reported here.

METHODS

Samples were collected at five stations on Voyage 18 of *S.A. Agulhas* during February/March 1981 in an area close to the Antarctic continent (Fig. 1). Water samples were drawn from three depths corresponding to the 100- (surface), 40- and 8-per cent light levels, as estimated from secchi disc measurements. Temperatures were measured with

a Neal Brown C.T.D. Salinity samples were analysed with an inductively coupled salinometer and salinities were calculated from the UNESCO International Oceanographic Table of 1966. Chlorophyll *a* was measured by the fluorometric method of Strickland and Parsons (1972). The nutrient concentrations in filtered samples were analysed on a Technicon Autoanalyser by the methods of Strickland and Parsons (*op. cit.*) for phosphate and nitrate, and of Grasshoff (1965) for silicate.

Simulated *in situ* carbon-14 incubations were performed by adding 4-6 μCi of $\text{NaH}^{14}\text{CO}_3$ to 120-ml water samples. The samples were then incubated at the ambient temperature of the seawater in a deck incubator under natural light for 4-6 hours. Light intensities were reduced to 100, 40 and 8 per cent of the surface intensity by means of metal screening. Incubations were terminated by filtration of the samples through 47-mm Nucleopore GC-50 glass-fibre filters. The filters were rinsed thoroughly with filtered seawater and stored frozen in 2 ml of distilled water until analysis.

The procedure of Li *et al.* (1980), slightly modified, was used for the differential extraction of the filtered samples. Thawed filters were extracted with chloroform/methanol/water (2.5 ml : 5 ml : 2 ml) at 5°C , filtered and washed with 2.5 ml of chloroform. Distilled water (2.5 ml) was added to the combined filtrate and the chloroform and methanol-water layers separated by centrifugation. The filters were extracted further with 6 ml of hot 5-per cent trichloroacetic acid (TCA) for 30 minutes and 5 ml of cold 5-per cent TCA. A 2-ml aliquot of each of the liquid fractions (the chloroform aliquot

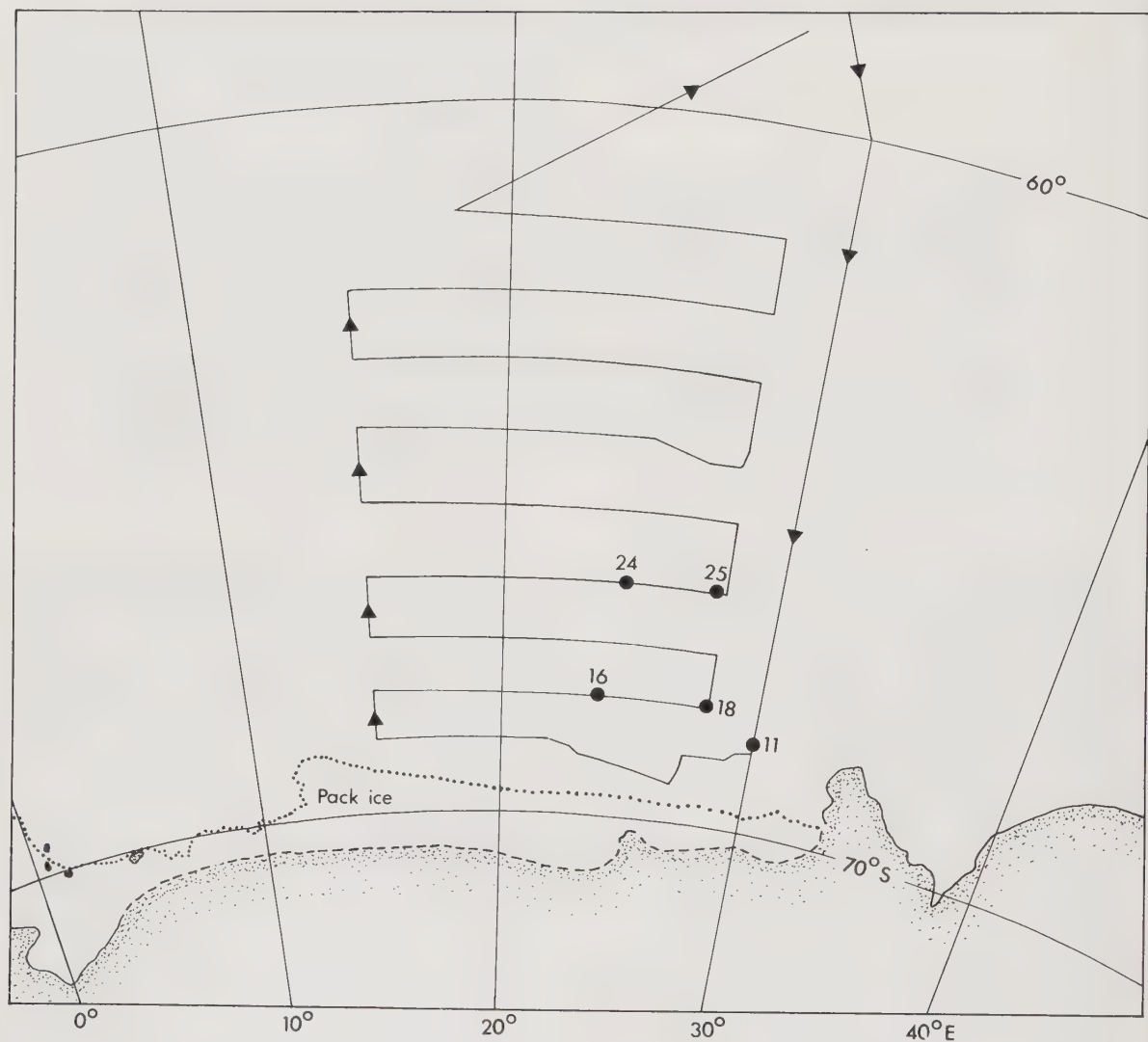


Fig. 1: Cruise track of S.A. Agulhas Voyage 18 (FIBEX) showing the positions of stations

was evaporated to dryness first) and the filter residues were assayed for radioactivity in Picofluor-30 on a Packard Prias liquid scintillation counter. Counting efficiency was determined with an external standard.

The methanol-water fraction contained predominantly low-molecular-weight metabolites, the chloroform fraction lipid, the TCA-soluble fraction polysaccharide and the TCA-insoluble fraction protein.

RESULTS

The temperatures and salinities, and the nutrient and chlorophyll *a* concentrations are summarized in Table I. Neither temperature nor salinity changed significantly with depth, but at two stations the temperatures were below 0°C. Concentrations of the major nutrients were uniformly high, and there was no indication of deficiency at any of the

Table 1: Physical, chemical and chlorophyll data from five stations in the Southern Ocean

Station	Depth (m)	Salinity (‰)	Temperature (°C)	Nutrient concentration ($\mu\text{g-at}\cdot\ell^{-1}$)			Concentration of chlorophyll <i>a</i> ($\mu\text{g}\cdot\ell^{-1}$)
				$\text{NO}_3^- - \text{N}$	$\text{PO}_4^{3-} - \text{P}$	$\text{SiO}_4^{4-} - \text{Si}$	
11	0	33,17	-0,9	22,1	2,54	60,3	0,05
	10	33,21	-0,9	23,0	1,46	47,1	0,10
	27	33,90	-0,4	22,6	1,51	47,3	0,14
16	0	33,81	+0,3	23,2	1,78	51,5	0,08
	10	33,82	+0,3	22,8	1,78	51,3	0,07
	27	33,82	+0,3	19,5	1,47	46,5	0,07
18	0	34,01	-0,2	29,2	1,89	57,4	0,05
	11	34,00	-0,2	27,4	1,86	56,7	0,08
	31	34,10	-0,2	29,5	1,87	57,1	0,08
24	0	33,94	+1,0	26,7	2,16	63,2	0,03
	10	33,94	+1,0	26,2	2,75	62,2	0,04
	28	33,94	+1,0	28,1	2,16	66,1	0,04
25	0	33,79	+1,1	25,2	2,10	53,5	0,05
	8	33,86	+1,1	24,9	1,88	47,2	0,03
	21	33,86	+1,1	27,3	2,25	48,1	0,04

stations. Chlorophyll *a* concentrations were very low indicating a low standing stock of phytoplankton. The communities at all the stations were dominated by diatoms, with species of the genera *Nitzschia*, *Chaetoceros*, *Corethron*, *Coscinodiscus* and *Rhizosolenia* the most abundant (Hampton 1981).

The pattern of photosynthesis at the five stations is illustrated in Figure 2. At Stations 11 and 18 most of the carbon-14 was detected in the low-molecular-weight fraction, and incorporation into the lipid and polysaccharide fractions was less than into protein. This pattern was the same for all three light intensities. At Stations 16, 24 and 25 a different pattern emerged. Most of the radioactivity was measured in the protein fraction, and considerably less activity was detected in the other fractions. Again, this pattern was the same for all three light intensities.

DISCUSSION

At Stations 11 and 18 (Fig. 2), where temperatures were below 0°C, it appears that the rate of synthesis of lipid, polysaccharide and protein was slow, because most of the assimilated carbon was detected in the low-molecular-weight fraction. In

contrast, at Stations 16, 24 and 25 (Fig. 2), where temperatures were above 0°C, carbon was rapidly assimilated into protein at the expense of assimilation into lipid and polysaccharide. These patterns occurred at all of the light intensities examined, and reduction in light intensity did not significantly change the proportion of carbon incorporated into the various fractions.

The results of this study were different from those observed in temperate waters such as those of the southern Benguela Current. Barlow (1982a, b) has shown that, in the upper euphotic zone, phytoplankton in water with a temperature higher than 10°C and an adequate supply of nutrients assimilates more carbon-14 into the polysaccharide fraction than into protein. A decrease in light intensity near the bottom of the euphotic zone, however, increased the proportion of carbon incorporated into protein at the expense of that into polysaccharide. Similar observations have been made by Morris and Skea (1978) in the Gulf of Maine.

Another study of carbon assimilation in Southern Ocean phytoplankton communities by Smith and Morris (1980a, b) has shown that a significant synthesis of lipid can occur at extremely low temperatures (<-1°C). This effect was enhanced by the additional stress of low light intensities. Synthesis of lipid by phytoplankton in the present study was not at all significant. It appears that the pattern

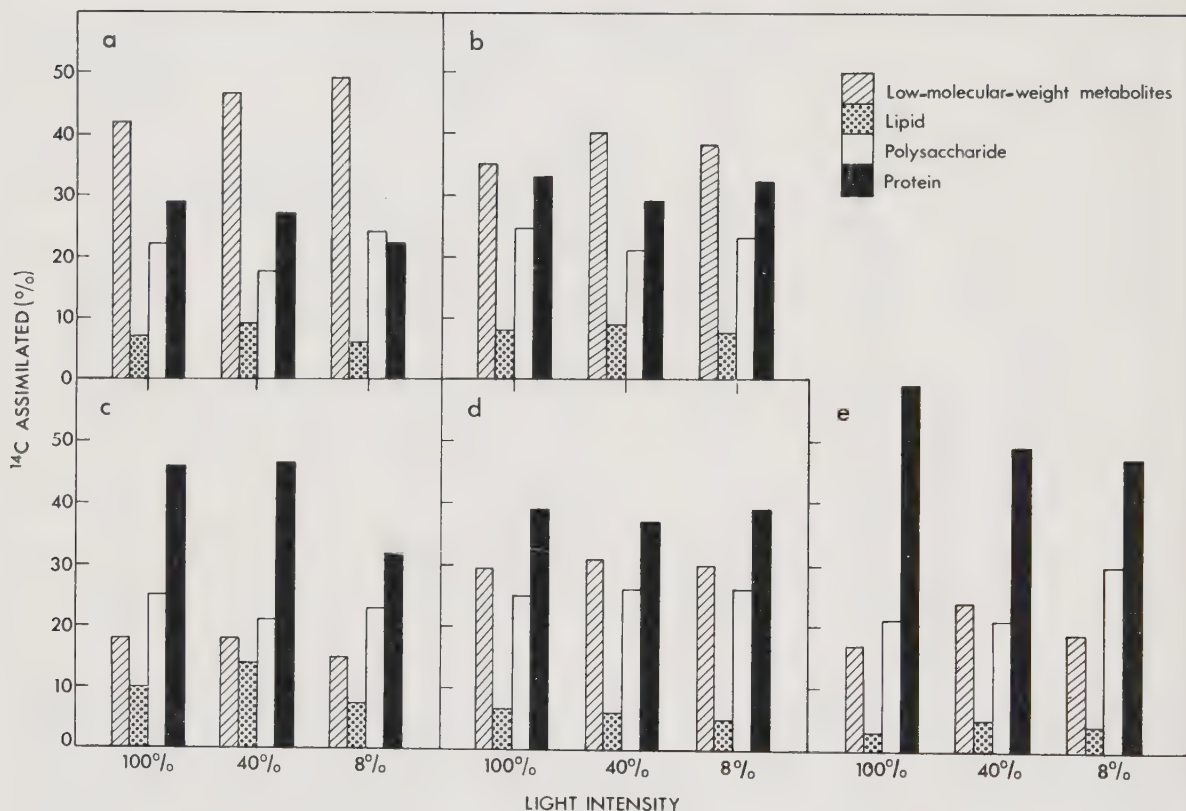


Fig. 2: The pattern of carbon-14 assimilation into different fractions when water samples drawn from depths corresponding to the 100-per-cent (surface), 40-per-cent and 8-per-cent light levels were incubated at those light intensities for 4-6 hours — (a) Station 11, ambient temperature -0.9°C ; (b) Station 18, ambient temperature -0.2°C ; (c) Station 16, ambient temperature $+0.3^{\circ}\text{C}$; (d) Station 24, ambient temperature $+1.0^{\circ}\text{C}$; (e) Station 25, ambient temperature $+1.1^{\circ}\text{C}$.

observed by Smith and Morris (*op. cit.*) was unique for phytoplankton in a polar region. Their investigations were conducted in the spring (September-October), and exposure of algal cells to very low temperatures in the dark under the Antarctic ice cap during the long winter could have induced the synthesis of high-energy lipid products at the expense of synthesis of polysaccharide and protein (I. Morris, University of Maryland, personal communication).

It may be concluded from the conditions reported here that phytoplankton communities are able to synthesize protein at a rapid rate throughout the euphotic zone in a polar region when temperatures are between 0 and 2°C . At temperatures lower than 0°C , protein synthesis appears to be reduced, and a large proportion of the assimilated carbon is stored in the low-molecular-weight metabolites.

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PHYTOPLANKTON PRODUCTION MEASURED *IN SITU* AND UNDER SIMULATED *IN SITU* CONDITIONS IN THE SOUTHERN BENGUELA UPWELLING REGION

P.C. BROWN

Simulated *in situ* phytoplankton production measurements are compared with actual *in situ* measurements in a nearshore upwelling area in the southern Benguela Current region. Estimates of oxygen production simulated on deck were slightly higher than *in situ* estimates. This fact is not attributed to differences in the spectral composition of the light, but it may be caused by slightly higher light levels and temperatures in the deck incubator. ^{14}C uptake experiments do not show significant differences, but more data are required to draw firm conclusions. However, the differences observed between simulated and *in situ* measurements are small relative to other experimental errors. Therefore, because of its convenience, it is suggested that, when ship's time is limited, the simulated *in situ* technique may be employed in Benguela waters.

Gesimuleerde *in situ*-fitoplanktonmetings word vergelyk met werklike *in situ*-metings in 'n opwellingsgebied digby die kus in die suide van die Benguela-stroomstelsel. Suurstofproduksieramings wat op dek gesimuleer is, was effens hoër as *in situ*-ramings. Dit word nie toegeskryf aan verskille in die spektrum-samestelling van die lig nie, maar 'n moontlike oorsaak is effens hoër ligvlakke en temperature in die dekinubator. ^{14}C -opnameproewe toon geen beduidende verskille nie, maar nader inligting is nodig voordat gevolgtrekkings met sekerheid gemaak kan word. Die verskille wat tussen gesimuleerde en *in situ*-metings waargeneem is, is egter klein in vergelyking met ander eksperimentele foute. Geriefshalwe word dus aan die hand gedoen dat, in geval skepsyd beperk is, die gesimuleerde *in situ*-tegniek in Benguela-waters gebruik kan word.

Phytoplankton productivity is commonly measured directly by incubating water samples in the sea at the depths from which they were drawn (the *in situ* method), or in an incubator on deck under natural light reduced with the aid of neutral-density screens (the simulated *in situ* method), or in an incubator in the laboratory with a constant artificial light source (incubator method). Indirectly, production is often estimated from measurements of such features as the concentration of chlorophyll *a* and natural irradiance (modelling method).

Each of these methods has inherent sources of error (Finenko 1978). *In situ* measurements have long been considered the simplest and most reliable for estimation of total primary production in the euphotic zone (Strickland 1960, Finenko *op. cit.*). However, this time-consuming method is often avoided because the prolonged delays severely limit the area of ocean that can be sampled. The variability of natural sunlight also makes it difficult to estimate the average production of an area from one measurement and to compare the productivity of two bodies of water measured under different weather conditions.

Steeman-Nielsen (1952) partly overcame these problems by incubating water samples on board ship in a constant-light incubator. Variations on this method have been used extensively, but most measure potential production rather than the production that would occur naturally. A better understanding of the responses of phytoplankton to different en-

vironmental factors subsequently enabled workers to use incubator production values to estimate actual daily production with a reasonable amount of confidence (Gargas *et al.* 1976, Jitts *et al.* 1976, Fee 1977). Nevertheless, *in situ* measurements remain the most realistic until artificial light more closely approximates natural submarine light. Another practical constraint favouring *in situ* measurements is that the equipment necessary for constant-light experiments is expensive.

As a compromise, the simulated *in situ* method is often used. However, the simulation of submarine light for production measurements is difficult (Jerlov and Nygaard 1969, Yentsch 1974, Steeman-Nielsen 1975, Jitts *et al.* 1976, Parsons *et al.* 1977) mainly because:

- (a) the action spectrum of phytoplankton species or populations may be quite different from the spectral response of the light sensor used to determine the submarine light levels;
- (b) the optical filters used to simulate submarine light in incubators do not necessarily duplicate the transmission characteristics of the water.

Jerlov (1951) described three optical types of oceanic water and nine types of coastal water. They ranged from clearest oceanic water, where blue light penetrates the deepest, to the most turbid coastal waters, where green to yellow light penetrates farthest. Despite the desirability of matching both the intensity and quality of light with *in situ* conditions, as is sometimes attempted in relatively uniform

oceanic waters (Jitts *et al.* 1976), the practical difficulties involved in more optically variable water masses led Ryther and Yentsch (1970) to recommend the use of spectrally neutral filters for general use, so that only light intensity is simulated. The extremely variable conditions in the highly productive coastal upwelling region off the Cape Peninsula precluded the use of coloured filters in incubators simulating *in situ* conditions for the same reasons. The present study was designed to compare *in situ* measurements of primary production with simulated *in situ* measurements in the southern Benguela region.

METHODS

Water samples were taken with 5- or 7-ℓ N.I.O. bottles from the 100-, 50-, 25-, 10- and 1-per-cent light depths. These depths were established by means of an underwater quantum sensor (Lambda LI-192S) as recommended by the SCOR Working Group 15 (Scientific Committee on Oceanic Research 1974). Subsamples were taken for the determination of salinity, nutrients, chlorophyll *a* and phytoplankton production. A bathythermograph (BT) temperature profile was recorded.

Phytoplankton production was measured by either the oxygen (12 experiments) or ^{14}C uptake (seven experiments) methods, modified from Strickland (1960) and Strickland and Parsons (1972) respectively. Replicate production samples from each depth were incubated both *in situ* and in a deck incubator, where *in situ* light levels were simulated in light bottles coated with a spectrally neutral mixture of clear varnish and black polyurethane paint (referred to in future as neutral density bottles). The required percentage transmission of light was attained by altering the proportions of paint and varnish in the mixture. In several experiments a third set of samples was incubated in similar neutral density bottles at the sea surface, away from the ship and alongside the *in situ* set, in order to investigate any "ship effect" on the deck incubator.

When enough data were available, *in situ* production estimates (P_i) and simulated *in situ* production estimates in the deck incubator (P_d) and on the sea surface (P_s) were compared by means of the Wilcoxon signed-ranks test (Dixon 1977). The mean P_d/P_i , P_s/P_i and P_d/P_s values were calculated (negative production was omitted). The overall effect of the different incubation methods on production estimates in the euphotic zone as a whole was ascertained by comparing the integrated production estimates, $\int P_i$, $\int P_d$, and $\int P_s$, (mg C m^{-2}). Because measurements at the 1-per-cent light level were mostly below the limits of precision of the oxygen-production method, they were not used in the comparison. The mean production estimate at the

1-per-cent light level was used to calculate integrated production for each experiment.

RESULTS AND DISCUSSION

Oxygen production

Production estimates are presented in Table I. In Table II, the mean P_d/P_i , P_s/P_i and P_d/P_s values are given together with the results of the Wilcoxon test (which compares numerator and denominator).

Simulated estimates of *in situ* production on deck (P_d) were significantly higher than those estimated *in situ* (P_i) at each light level, except at the sea surface (100-per-cent light level). In the latter case, there was no significant difference, although the mean P_d estimate was 34 per cent greater than that of the mean P_i .

Although there were insufficient data to state unequivocally that there is no difference between simulated *in situ* estimates of production at the sea surface (P_s) and *in situ* estimates (P_i), the mean values of both $\int P_s/\int P_i$ (integrated production estimates) and P_s/P_i (for individual light levels) are close to unity. In addition, when values from all the light levels were grouped ($n = 19$), P_s and P_i were not significantly different (Table II).

In only three experiments was production measured by means of all three incubation methods simultaneously. Although not conclusive, results suggest that simulated estimates of *in situ* production on deck (P_d) were greater than those at the sea surface (P_s).

It appears that P_d overestimates P_i , whereas P_s is similar to P_i . It is likely, therefore, that the spectral composition of the incubation light (which would have been the same in the deck incubator and at the sea surface) is not responsible for the difference between estimates of simulated *in situ* production on deck and those made *in situ*. The disagreement between the two sets of measurements is more likely to be related to differences in light intensity and/or temperature. Because thick glass-walled incubation bottles were used, ultra-violet light was excluded from all samples and was unlikely, therefore, to influence production rates (cf. Jitts *et al.* 1976).

Reflection from the white superstructure of the ship may have caused the light incident on the deck incubator to be greater than that on the sea surface. An increase in light generally causes an increase in production until the phytoplankton becomes light saturated (Parsons *et al.* 1977). Production rates of populations at the 100- and 50-per-cent light levels were unlikely to be limited by lack of light. Deeper populations were probably not light saturated, however, and could be expected to show higher production rates when incubated at slightly higher light

Table I: Oxygen production estimates (P_i = *in situ* production; P_d = simulated *in situ* production in a deck incubator; P_s = simulated *in situ* production at the sea surface; $\int P$ = production integrated in the euphotic zone)

Experiment	Date	Depth (m)	Light level (%)	Net production (mg C·m ⁻³ ·h ⁻¹)			Integrated production (mg C·m ⁻² ·h ⁻¹)		
				P_i	P_d	P_s	$\int P_i$	$\int P_d$	$\int P_s$
1	24/1/78	0	100	15,1	—	20,6	348	—	257
		2,5	50	—	—	—			
		5	25	15,8	—	14,5			
		8	10	39,4	—	25,5			
		20	1	-9,2	—	-11,2			
2	26/4/78	0	100	8,9	15,6	—	94	116	—
		2,5	50	15,2	19,0	—			
		4	25	17,8	19,5	—			
		9	10	-3,1	-1,1	—			
		19,5	1	-1,2	-1,7	—			
3	27/4/78	0	100	8,4	10,6	—	162	105	—
		2,5	50	10,5	15,6	—			
		5	25	16,9	15,6	—			
		9	10	10,1	0,6	—			
		21	1	1,6	-5,6	—			
4	6/7/78	0	100	45,2	50,8	40,2	245	351	264
		2,5	50	51,0	58,6	49,7			
		5,5	25	15,4	36,8	23,4			
		10	10	-19,4	7,2	-5,0			
		18	1	-18,4	-5,0	-11,2			
5	17/10/78	0	100	86,8	74,0	—	509	678	—
		1	50	85,8	152,5	—			
		2	25	84,9	132,7	—			
		4	10	64,8	74,0	—			
		10	1	-6,0	1,3	—			
6	18/10/78	0	100	49,9	90,0	—	486	648	—
		1,5	50	106,2	144,3	—			
		3	25	74,1	100,9	—			
		5	10	48,8	58,1	—			
		9	1	4,1	7,4	—			
7	24/10/78	0	100	—	66,4	—	451	511	—
		2	50	53,0	34,6	—			
		4	25	39,6	85,4	—			
		7	10	9,1	10,0	—			
		17	1	-0,7	14,0	—			
8	14/12/78	0	100	19,5	—	23,4	568	—	562
		2	50	—	—	38,5			
		5	25	23,4	—	16,2			
		9,5	10	17,8	—	20,1			
		30	1	8,9	—	6,6			
9	18/12/78	0	100	22,3	31,3	—	332	379	—
		2,5	50	20,7	35,2	—			
		5,5	25	17,2	25,1	—			
		10,5	10	7,4	18,4	—			
		17,5	1	5,3	13,4	—			
10	12/1/79	0	100	23,0	—	18,5	—	—	—
11	13/3/79	0	100	129,5	129,5	119,5	795	865	699
		1	50	138,4	209,9	179,2			
		2	25	147,4	148,0	120,6			
		4	10	83,8	83,2	57,5			
		9,5	1	10,6	7,2	31,3			
12	16/3/79	0	100	57,0	89,9	41,9	503	724	671
		1,5	50	101,2	131,2	111,7			
		3	25	97,9	131,8	98,8			
		5	10	42,2	68,7	88,8			
		10	1	-12,0	-0,6	-1,7			

Table II: Comparisons between production estimates made *in situ* (P_i) and under simulated *in situ* conditions in a deck incubator (P_d) and at the sea surface (P_s) measured by means of the oxygen method at different light intensities (mean values and the results of the Wilcoxon signed-ranks test comparing numerator and denominator are given)

Light level (%)	P_d/P_i			P_s/P_i			P_d/P_s		
	Mean	Probability	<i>n</i>	Mean	Probability	<i>n</i>	Mean	Probability	<i>n</i>
100	1,34	NS	8	0,98	NS	6	1,49	—	3
50	1,35	*	9	1,12	—	3	1,17	—	3
25	1,48	**	9	0,94	NS	5	1,38	—	3
10	1,42	*	9	1,16	NS	5	1,11	—	3
1	Production levels below the level of precision								
All levels (100% - 10%)	1,36	**	35	1,03	NS	19	1,23	**	12
$\bar{P}$ (m^{-2})	1,20	**	9	1,06	NS	5	1,13	—	3

* Probability ≤ 5 per cent

** Probability ≤ 1 per cent

NS = Not significantly different

— = No test, too few replicates

n = Number of replicates

levels on deck. This appears to be the case for samples at the 25- and 10-per-cent levels.

Another factor which might affect production rates is temperature. Temperature decreased with depth, so that the simulated *in situ* samples from low light levels were incubated at higher temperatures than *in situ* samples. The effect of temperature on the rate of photosynthesis is not well understood, but it is thought to manifest itself only after light saturation (Gessner 1970). Consequently, phytoplankton subjected to the greatest changes in temperature (i.e. the deep samples) was unlikely to be affected by an increase in temperature because it was incubated at low light levels. Furthermore, the temperature difference between the 100- and 1-per-cent light levels is usually less than 2°C because strong thermoclines are seldom established in such a dynamic upwelling system. Even in those cases where the temperature difference was greater than 2°C, the simulated production measurements on the sea surface were not noticeably higher at the low light levels (1, 10 and even 25 per cent). For the shallow samples at saturating light levels (100 and 50 per cent) the temperature difference between samples incubating *in situ* and at the sea surface was negligible, and production measurements were not significantly different. The temperature in the deck incubator was usually 1 - 2°C higher than at the sea surface. This higher temperature was unlikely to affect rates of production at low light levels (for reasons discussed above), but it may have been responsible for the higher production rates at the 100- and 50-per-cent

light levels on deck.

It is likely that the increase in production on deck at high light levels (100 and 50 per cent) was caused by the slightly higher temperature in the deck incubator, whereas at low light levels (25 and 10 per cent) increased production was the result of an increase in incubating light. It is possible that both the increased light and temperature on deck simultaneously affected the rate of production (Platt *et al.* 1977), but that the effect of light dominated at limiting light levels whereas that of temperature dominated at saturating light levels.

¹⁴C uptake

Of the seven ¹⁴C experiments, only three (Nos. 15, 16 and 17) included simulated *in situ* production estimates at the sea surface (P_s) — see Table III. These three experiments show trends similar to those obtained from the oxygen method, i.e. simulated *in situ* production estimates on deck (P_d) higher than those at the sea surface (P_s) and higher than *in situ* estimates (P_i) — see Table IV. In the other four experiments (Nos. 13, 14, 18 and 19), the simulated *in situ* production measurements on deck (P_d) underestimate the *in situ* measurements (P_i) and tend to cancel out the opposite trends in Experiments 15-17. Therefore, when all the experiments are grouped, no significant differences between production estimates on deck and those made *in situ* are observed (Table IV). The reason for the different trends is not known.

Table III: ^{14}C uptake production estimates (P_i = *in situ* production; P_d = simulated *in situ* production in a deck incubator, P_s = simulated *in situ* production at the sea surface; $\int P$ = production integrated in the euphotic zone)

Experiment	Date	Depth (m)	Light level (%)	Net production ($\text{mg C}\cdot\text{m}^{-3}\cdot\text{h}^{-1}$)			Integrated production ($\text{mg C}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$)		
				P_i	P_d	P_s	$\int P_i$	$\int P_d$	$\int P_s$
13	7/12/77	0	100	62.02	23.81	—	272	152	—
		1.5	50	52.54	31.02	—			
		8.5	1	1.01	0.28	—			
14	16/5/78	0	100	4.38	4.27	—	64	44	—
		6	50	3.96	3.51	—			
		11.5	25	2.50	1.31	—			
		19.5	10	0.97	0.26	—			
		40	1	-0.70	0.11	—			
15	27/6/78	0	100	4.78	5.88	5.67	108	128	117
		6.5	50	7.11	7.43	6.87			
		13	25	4.32	6.43	5.46			
		22	10	1.13	2.33	—			
16	4/7/78	0	100	13.03	13.72	10.22	216	245	284
		4	50	16.57	19.69	17.00			
		8	25	14.84	17.48	10.35			
		13.5	10	5.25	5.56	15.12			
		27	1	0.76	0.27	0.26			
17	22/8/78	0	100	1.32	1.23	1.23	26	48	25
		4	50	1.30	1.90	1.92			
		9	25	2.16	2.69	0.85			
		15	10	0.68	2.46	1.16			
		29	1	0.13	-0.87	-0.40			
18	26/4/78	0	100	6.30	4.96	—	86	71	—
		3	50	9.21	5.81	—			
		4.5	25	4.57	7.65	—			
		9.5	10	5.01	3.04	—			
		20	1	0.42	0.22	—			
19	27/4/78	0	100	2.77	3.77	—	75	44	—
		3.5	50	4.61	4.52	—			
		6	25	6.14	3.25	—			
		10	10	4.21	1.56	—			
		22	1	0.39	0.06	—			

Too much significance should not be placed on these differences, however, as there are insufficient data to draw firm conclusions.

MacIsaac and Dugdale (1976) used ^{15}N uptake to estimate production, and found that *in situ* estimates were generally higher than simulated estimates on deck in the north-west African upwelling region, whereas in the oligotrophic western Mediterranean they observed no significant differences. They gave no satisfactory explanation for their observations but recommended that the technique of simulated *in situ* incubation be continued.

The experimental error in any single ^{14}C production measurement is at least 30 per cent, even if all

precautions are taken (Steeman-Nielsen 1975). The method of incubation may increase this error considerably. For example, production samples are usually incubated at fixed light depths, whereas under natural conditions phytoplankton populations may experience a far more variable light regime because of their vertical movement in the water column. Marra (1978) found that simulating the latter conditions gave estimates of integrated photosynthesis 19-87 per cent higher than estimates calculated for measurements at fixed light depths. In the present study, the simulated integrated production estimates are about 20 per cent higher than estimates from *in situ* measurements (Table II). Because this

Table IV: Comparisons between production estimates made *in situ* (P_i) and under simulated *in situ* conditions in a deck incubator (P_d) and at the sea surface (P_s) measured by means of the ^{14}C method at different light intensities (mean values and the results of the Wilcoxon signed-ranks test comparing numerator and denominator are given)

Light level (%)	Experiments 13 - 19			Experiments 15 - 17								
	P_d/P_i			P_d/P_i			P_s/P_i			P_d/P_s		
	Mean	Probability	<i>n</i>	Mean	Probability	<i>n</i>	Mean	Probability	<i>n</i>	Mean	Probability	<i>n</i>
100	0,96	NS	7	1,07	—	3	0,97	—	3	1,13	—	3
50	0,98	NS	7	1,23	—	3	1,16	—	3	1,08	—	3
25	1,10	NS	6	1,30	—	3	0,78	—	3	2,01	—	3
10	1,33	NS	6	2,24	—	3	2,29	—	2	1,24	—	2
1	Data few and variable											
All levels (100% - 10%)	1,08	NS	26	1,46	*	12	1,21	NS	11	1,38	*	11
P (m^{-2})	0,98	NS	7	1,39	—	3	1,12	—	3	1,29	—	3

* Probability ≤ 5 per cent

NS = Not significantly different

— = No test, too few replicates

n = Number of replicates

error is less than, or at worst equal to, the errors mentioned above, it would appear to be acceptable to use the simulated *in situ* technique for measuring production rates in the southern Benguela coastal upwelling region.

CONCLUSIONS

When simulated *in situ* oxygen production was determined in a deck incubator, measurements overestimated *in situ* production at discrete depths by between 34 and 48 per cent, and in the whole euphotic zone (integrated production) by about 20 per cent. It appears that higher light levels on deck (possibly caused by reflection from the white superstructure of the vessel) may be responsible for the increase in production at limiting light levels (10 and 25 per cent). However, at saturating light levels (50 and 100 per cent), the slightly higher temperatures (1–2°C) in the deck incubator seem responsible for the increased rate of production.

No significant differences were observed with the ^{14}C method because of insufficient data, and more measurements are required to draw firm conclusions.

The differences observed between measurements of production made *in situ* and under simulated *in situ* conditions are small compared with possible experimental errors. It is therefore suggested that the convenience of the technique of simulated *in situ*

incubation makes it an adequate method of measuring primary production in southern Benguela waters when ship's time is limited.

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THE EFFECT OF TEMPORARY EXPOSURE OF PHYTOPLANKTON TO MID-DAY IRRADIANCES ON *IN SITU* PRODUCTION ESTIMATES IN THE SOUTHERN BENGUELA UPWELLING REGION

P.C. BROWN

Phytoplankton samples taken for primary-production experiments to be made *in situ* may be exposed to high irradiances during manipulations on deck. The effects of such exposure were investigated in an upwelling area in the southern Benguela region. Prolonged exposure appears to inhibit production rates of samples from near the bottom of the euphotic zone (particularly below a thermocline), but for those from the sea surface it apparently stimulates production. That integrated production estimates ($\text{mg C} \cdot \text{m}^{-2}$) were not significantly affected suggests that the overestimate near the sea surface compensates for the underestimate deeper down. The short exposure (less than one minute) of samples when they are lowered into the sea for *in situ* incubation does not affect production estimates significantly. Nonetheless, results indicate that production samples should be shielded from bright light as much as possible during sampling, especially when the water column is strongly stratified.

Fitoplanktonmonsters wat vir *in situ*-proewe in verband met primêre produksie geneem is, kan tydens hantering op dek aan sterk straling blootgestel word. Die uitwerking van sodanige blootstelling is in 'n opwellingsgebied in die suide van die Benguela-stroomstelsel ondersoek. Skynbaar strem langdurige blootstelling produksiekoerse van monsters wat digby die bodem van die eufotiese sone geneem is (veral benede 'n termoklien), maar stimuleer die produksie vir dié wat by die see-oppervlak geneem is. Die feit dat geïntegreerde produksieramings ($\text{mg C} \cdot \text{m}^{-2}$) nie beduidend geaffekteer is nie, dui daarop dat die oorskatting naby die see-oppervlak vir die onderskatting dieper af vergoed. Die kortstondige blootstelling (minder as een minuut) van monsters wanneer hulle vir *in situ*-inkubasie in die see neergelaat word, affekteer produksieramings nie juis veel nie. Nietemin dui resultate daarop dat produksiemonsters soveel moontlik tydens monsterneming teen helder lig beskut behoort te word, veral wanneer die waterkolom goed gestratifiseer is.

It is well known that light intensity affects the photosynthesis of marine phytoplankton. The curve describing the relationship between photosynthesis and light (P v. I)—as shown in Figure 1—reflects the general response of phytoplankton to an increase in light intensity. Photosynthesis increases linearly with increasing light intensity, but when the phytoplankton becomes light saturated, the curve flattens out at an asymptotic value, P_{max} .

Further increase in light intensity eventually results in a decrease in the photosynthetic rate. Photo-inhibition has been attributed to various factors including enzyme inactivation, light damage because of either light or dark reactions and photorespiration (Harris and Piccinin 1977). Generalizations about depressions in the photosynthetic rate at high light intensities are difficult to make because the rate depends on experiment duration, adaptation time, temperature, light spectral composition etc. (Finenko 1978).

A practical problem associated with the phenomenon of photo-inhibition is that of exposure of deep water samples (used for photosynthetic measurements in the euphotic zone) to surface light levels during manipulation on deck. Light levels may reach $2\,000\text{--}3\,000\ \mu\text{E} \cdot \text{m}^{-2} \cdot \text{s}^{-1}$ at noon in summer off Cape Town (Sea Fisheries Institute, unpublished data). Therefore, phytoplankton from the 1-per-cent light

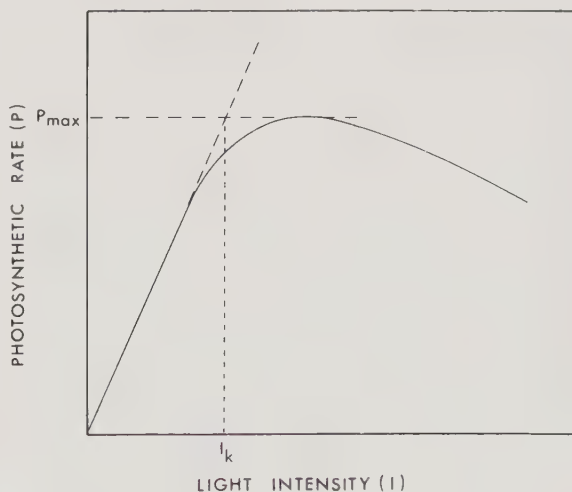


Fig. 1: Diagrammatic photosynthesis/light (P v. I) relationship. P_{max} = photosynthetic maximum (after Parsons *et al.* 1977)

depth are exposed to several times more light in a few minutes than they are over the whole day under normal conditions. Although precautions are normally taken to shade water samples from the light at

the surface, they are inevitably exposed when lowered from a ship for *in situ* incubation.

Dyson *et al.* (1965) and Watt (1965) independently devised incubation systems to avoid this problem. Sample bottles were filled, automatically inoculated with ^{14}C and allowed to incubate *in situ*, thereby not being exposed to surface light prior to incubation. A problem with this method is that another sampler has to be used to retrieve water samples for measuring the usual accessory parameters (e.g. chlorophyll *a*, nutrients, oxygen). Because of patchiness in phytoplankton distribution it is impossible to be sure of sampling the same "patch", and for this reason Dyson *et al.* (*op. cit.*) discontinued the method.

There are some inconsistencies in the literature concerning the light intensity and the period of exposure necessary for photo-inhibition to take effect. Goldman *et al.* (1963) found that, after storing lake water under dim light ($50\text{ ft-c} = 3,5\ \mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$) and low temperature (4°C), and then exposing it to direct sunlight for 5 minutes, ^{14}C assimilation was reduced by between 17 and 31 per cent. It took about 4 hours for the phytoplankton to recover to the same rate of ^{14}C uptake as that of the control samples. Exposure to direct sunlight for 1 hour increased the recovery time to 20 hours, thereby indicating that the recovery time was a function of the exposure period. On the other hand, Takahashi *et al.* (1971) found that photo-inhibition was not generally observed over short periods (e.g. 10 minutes), but that it might be caused by longer exposures and could increase in magnitude with time.

Falkowski and Owens (1978) found that, for six species of phytoplankton, inhibition of oxygen production commenced after only 6 minutes' exposure to light levels ranging between 2 000 and 6 000 $\mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ and that such inhibition was completely reversible. Their experiments were carried out with cultures grown at $250\ \mu\text{E}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$. Had the stock cultures been acclimatized to a different light level, the light intensity at which inhibition would have occurred might have been different. It is possible that the light intensity used by Takahashi *et al.* (1971) was not high enough to cause inhibition after short exposures. Doty *et al.* (1965) found that exposure of natural phytoplankton populations to bright sunlight for even a few minutes caused a strong depression in photosynthetic rates.

The present set of experiments is designed to investigate the effect of surface light intensities (as encountered during sampling) on rates of phytoplankton photosynthesis in the euphotic zone of the southern Benguela coastal upwelling area.

METHODS

A total of 13 experiments was conducted between January 1978 and March 1979 under a wide range of concentrations of chlorophyll *a* and nutrients at two stations off the Cape Peninsula. One station was situated about 2 km off Oudekraal ($33^\circ 58'\text{S } 18^\circ 20,6'\text{E}$) and the other the same distance north of Robben Island ($33^\circ 46,4'\text{S } 18^\circ 22,3'\text{E}$). Water samples were drawn from a series of depths ranging from the surface to the bottom of the euphotic zone by means of 5- ℓ or 7- ℓ N.I.O. bottles. The 1-per-cent light level was taken to be the bottom of the euphotic zone. Light was measured with an underwater quantum sensor (Lambda LI—192 S) as recommended by the SCOR Working Group 15 (Scientific Committee on Oceanic Research 1974). Owing to problems with the light metering system, light depths were calculated only approximately at the time of measurement and corrections were made later. Consequently, percentage light levels were grouped into five categories. The mean values (and ranges) were: 100%; 43% (30—57%); 22% (18—28%); 8,4% (3—13%); 0,8% (0,4—1,4%). Subsamples were taken for analysis of salinity, nutrients, chlorophyll *a* and primary production. A bathythermograph (BT) temperature profile was recorded.

N.I.O. bottles were painted black to prevent the exposure of water samples to bright sunlight as they were winched on board. Subsamples for measurement of primary production were drawn (in the shade) into 125-ml glass reagent bottles and stored at sea surface temperatures until the incubation was started (about 1 h00). On average, incubation lasted about 4 hours, but occasionally it took as little as $3\frac{1}{2}$ or as much as 6 hours. The oxygen method (modified from Strickland 1960) was used to measure primary production (except for Experiment 3 when the ^{14}C method was used). Two initial bottles (only for the oxygen method), two dark bottles and six light bottles were filled for each incubation level. Of the light bottles, two were completely unprotected, i.e. exposed to surface irradiance from the time the samples were taken until they were suspended in the sea for *in situ* incubation. Two more were semi-protected, i.e. placed in small black bags which were removed immediately before the bottles were lowered into the sea. The last two were completely protected from surface irradiance, i.e. the black bags were taken off by SCUBA divers immediately the bottles reached their incubation depths in the sea. The net production values obtained from the protected sam-

Table I: Comparisons at different mean light intensities of net production estimates of water samples unprotected (U), semi-protected (S) and protected (P) from surface irradiances (mean values and the results of the Wilcoxon signed-ranks test comparing numerator and denominator are given)

Light category (%)	Range of light intensities (%)	S/P		U/P		U/S		Number of replicates <i>n</i>
		Mean	Probability	Mean	Probability	Mean	Probability	
100	—	1,17	*	1,60	**	1,36	**	9
43	30-57	1,08	NS	0,97	NS	0,93	NS	6
22	18-28	0,98	NS	1,02	NS	1,06	NS	9
8,4	3-13	0,84	NS	0,85	*	1,10	NS	10
0,8	0,4-1,4	Values below the limits of precision of the method						
Euphotic zone	—	0,95	NS	0,95	NS	1,06	NS	11

* Probability $\leq$ 5 per cent

** Probability $\leq$ 1 per cent

NS = Not significantly different

ples were assumed to be the true values.

The effects of the three conditions (unprotected, semi-protected and protected) on net production were compared separately for each light category by means of the Wilcoxon signed-ranks test (Dixon 1977). The overall effect in the euphotic zone was ascertained by comparing integrated values, i.e. production per square metre to the depth of the 0,8-per-cent light category. Because production values for the 0,8-per-cent light category were all below the limits of precision of the oxygen method, they could not be used in the comparison. Their mean value was used solely to calculate integrated production for each experiment.

Mean S/P (semi-protected/protected), U/P (unprotected/protected) and U/S (unprotected/semi-protected) values were calculated. Unreliable production estimates or those which were below the limits of precision of the method of measuring production were not used in the comparisons.

RESULTS

Production estimates under the three conditions (protected, semi-protected and unprotected) are given in Figure 2. Table I presents the mean S/P, U/P and U/S values and the results of the Wilcoxon signed-ranks test, which compares numerator and

denominator.

At the 100-per-cent light level (sea surface), semi-protected (S) and unprotected (U) production estimates were significantly higher than the protected (P) ones, and unprotected were higher than the semi-protected estimates. In the 43- and 22-per-cent categories, no significant differences were observed amongst the three conditions, whereas in the 8,4-per-cent category, unprotected were significantly lower than protected estimates. No significant differences were observed amongst integrated production estimates.

Results indicate that exposing water samples to surface irradiance prior to their incubation at the correct light level affects production rates in two ways. It may act either to stimulate production in populations adapted to high light levels, or to inhibit production in populations conditioned to low light levels.

At the 100-per-cent light level, exposure to surface irradiance merely served to increase the incubation time, thereby effectively increasing production. Even the slightly longer (at most five minutes) incubation period of the 100-per-cent semi-protected samples (compared with the protected ones) resulted in a small increase in production significant at the 5-per-cent level.

In the 43- and 22-per-cent light categories the increase in production due to increased light was probably countered by the inhibitory effect, with the

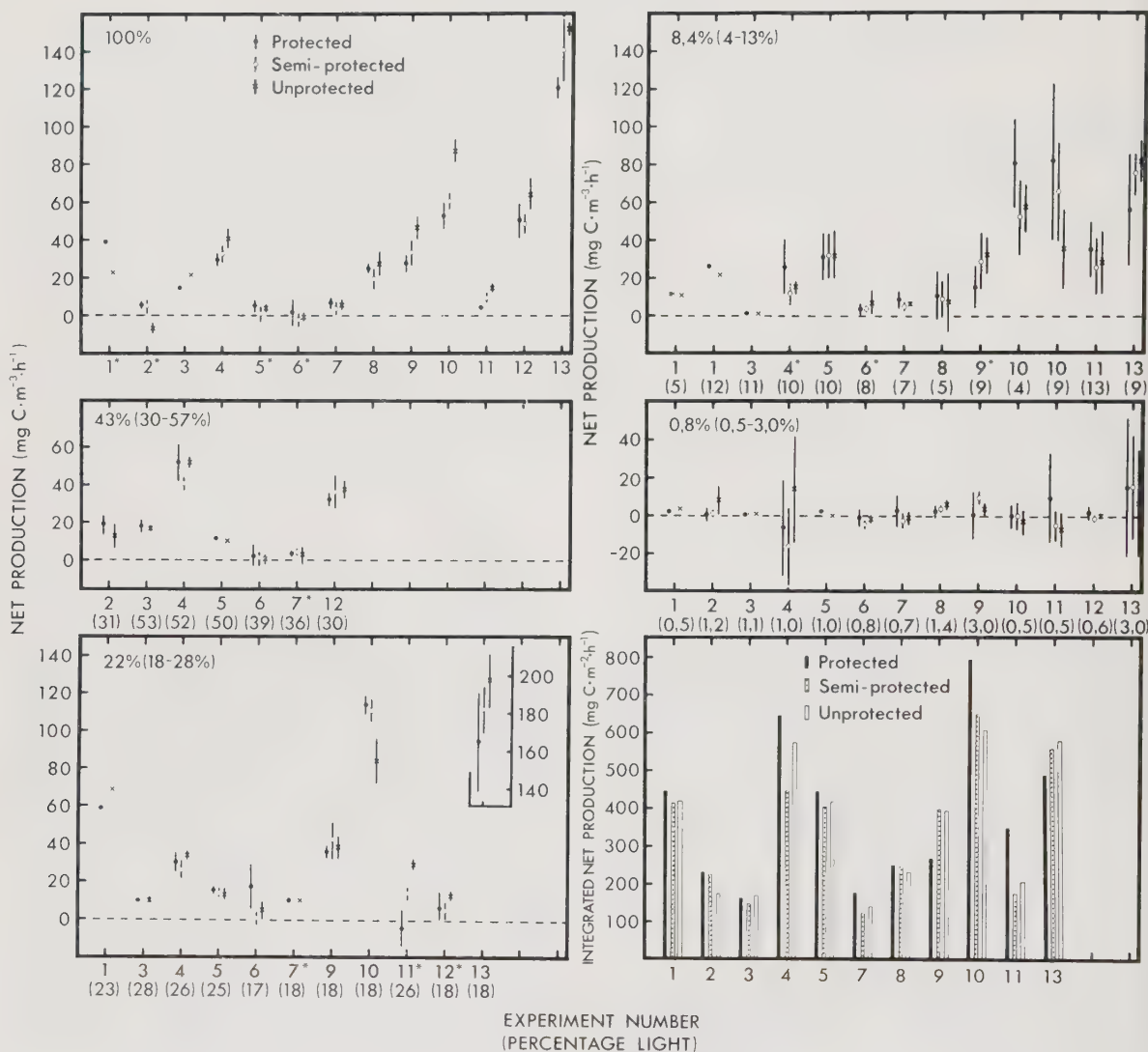


Fig. 2: The effect of exposing water samples to surface light prior to incubation at various light levels, and the integrated net estimates of primary production. Samples were protected (P), semi-protected (S) or unprotected (U) from surface light. The error bar is the range of the production estimate

result that no significant differences were observed. In the 8.4-per-cent light category, however, the inhibitory effect outweighed any possible increase in production as a result of increased light, so that the unprotected result was lower than that of the protected. Even though the semi-protected and protected estimates were not significantly different, the mean S/P value (0.84) lends evidence that even the

relatively short (approximately one minute) exposure to surface irradiance may have an inhibitory effect on production. Therefore, the period of exposure to surface light should be kept as short as possible.

In the 0.8-per-cent light category, the results would be anticipated to be similar to those found at the 8.4-per-cent light level, but the oxygen method is not

Table II: The effect of exposing primary-production samples taken from mixed and stratified water bodies to high surface light levels prior to incubation (mean U/P values and the results of the Wilcoxon signed-ranks test comparing numerator and denominator are given).

No thermocline			Thermocline present (i.e. stratified)					
Experiment	Light level (%)	U/P	Above thermocline			In or below thermocline		
			Experiment	Light level (%)	U/P	Experiment	Light level (%)	U/P
5	50	1,35	3	57	0,97	1	23	1,17
5	25	0,83	4	52	1,00	1	12	0,82
5	10	1,04	4	24	1,13	1	5	0,92
7	36	0,70	9	18	1,07	2	31	0,67
7	18	1,40	12	30	1,15	3	28	1,01
7	7	0,73	13	18	1,20	3	11	1,00
8	24	0,97	13	9	1,45	8	24	0,97
8	5	0,63				8	5	0,63
						10	18	0,73
						10	9	0,44
						11	13	0,81
Mean U/P		0,96			1,14			0,83
Probability		NS			*			*

* Probability $\leq$ 5 per cent
NS = Not significantly different

sensitive enough to detect significant differences at such low levels of production. However, even if the method of measurement were more sensitive, it is unlikely that the differences in production at the bottom of the euphotic zone would be large enough to contribute significantly to the total production in the euphotic zone.

No significant differences were found with integrated production estimates: apparently the over-estimates near the sea surface compensate for the underestimates deeper down.

DISCUSSION

Research by Platt *et al.* (1981) on natural diatom populations supports the findings reported here, particularly because diatoms dominate in Benguela waters (Barlow 1981, Olivieri 1981). Their curves of P_v vs. I show little inhibition of samples taken from the 50-per-cent light level, but intense inhibition of those from the 1-per-cent light level. This finding lends support to the widely held view that the light history of a phytoplankton population plays an important rôle in the response of phytoplankton to different light levels.

Savidge (1979) demonstrated that phytoplankton populations in a mixed water column showed a different response from those in a stratified water column. In a mixed water column, the long-term light histories of samples from different depths were

similar, with the result that P_{max} values were comparable. In stratified water, however, little mixing occurred between the two phytoplankton populations separated by the thermocline. Their light histories differed considerably, the shallower population receiving more light than the deeper one. For shallow samples taken in the late morning and afternoon, the curve for P_v vs. I indicated no inhibition at the higher light levels (linear response), whereas samples from below the thermocline displayed definite levelling off in the rate of photosynthesis with an increase in the intensity of incubating light. Savidge's (*op. cit.*) findings strongly suggest that the two populations were conditioned to different light levels.

In the series of experiments reported here the water column was sometimes completely mixed, and at other times a shallow thermocline was present. Results in Table II show little inhibition in samples above the thermocline, whereas those below or in the thermocline zone tend to be inhibited by exposure to surface light levels prior to incubation. In mixed water the results are variable and no definite trends are evident.

Strong winds and intense upwelling characterize the coastal water of the South-Western Cape in summer and stratification, if present, is usually poorly developed. The water column is more strongly stratified further off shore away from areas of active upwelling and on the south coast of South Africa, particularly over the Agulhas Bank. Conditioning of phytoplankton can be expected to be of

greater significance in these areas.

CONCLUSIONS

Exposing water samples from the euphotic zone to surface light levels prior to *in situ* incubation appears to have both a stimulatory and an inhibitory effect on production. The stimulatory effect decreases with depth, whereas the inhibitory effect increases. Consequently, estimates of production at the surface (in the 100-per-cent light category) were higher with the additional light, whereas those in deeper water (in the 8,4- and possibly the 0,8-per-cent light categories) were lower. Production estimates midway in the euphotic zone (in the 43- and 22-per-cent light categories) were not significantly altered by the excess light, the stimulatory effect apparently being countered by the inhibitory effect. Estimates of integrated production for the euphotic zone also appear to be unchanged by temporary exposure to bright light.

Results indicate that water samples taken from the euphotic zone for production measurements should be shaded from surface light as much as is practicable during operations on deck. However, when samples are lowered into the water for *in situ* incubation, the short exposure (less than one minute) to surface light does not affect production measurements significantly. The additional complication of trying to shade the samples until they are at the *in situ* light levels is, therefore, not justified, but the exposure period should be kept as brief as possible.

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A BRIEF EXPLOITATION OF THE STONE CRAB *LITHODES MURRAYI* (HENDERSON) OFF SOUTH WEST AFRICA, 1979/80

R. MELVILLE-SMITH

The stone crab *Lithodes murrayi* was exploited briefly off South West Africa between November 1979 and April 1980, the fishery being terminated when the catch per unit effort fell to an uneconomic level. The extent of the *L. murrayi* grounds is examined on the basis of catch-per-unit-effort data. The species is largely confined to a bathymetric corridor of 500 — 700 m off South West Africa. Prior to commercial fishing, there was a densely populated region between 24°00'S and 24°40'S, although the crabs were present in small numbers over a much larger area. Over 90 per cent of the fishing effort was applied in this area of high concentration, accounting for almost 95 per cent by mass of the total catch. Although the catch rate declined, the mean size of exploitable crabs and of undersize crabs stayed virtually constant. Some morphometric relationships and a factor for converting processed crab section mass to whole crab mass have been calculated.

Die klipkrap *Lithodes murrayi* is langs die kus van Suidwes-Afrika ontgin gedurende die kort tydperk November 1979 tot April 1980. Die vissery is gestaak toe die vangs per pogingseenheid tot 'n onekonomiese vlak gedaal het. Die omvang van die *L. murrayi*-gronde word op grond van vangs-per-pogingseenheid-data ondersoek. Die spesie word grotendeels in 'n batimetrieë strook tussen 500 en 700 m langs die kus van Suidwes-Afrika aangetref. Voor die aanvang van kommersiële ontginning was daar 'n dig bevolkte streek tussen 24°00'S en 24°40'S, hoewel die krappe oor 'n veel groter gebied yl versprei was. Meer as 90 persent van die vangpoging is toegespits op hierdie gebied van hoë konsentrasie, waar meer as 95 persent van die totale massa gevang is. Al het die vangkoers gedaal, het die gemiddelde grootte van ontginbare krappe en ondermaatse krappe feitlik konstant gebly. Enkele morfometrieë verhoudings is bereken, asook 'n faktor vir die omsetting van die massa van verwerkte krapseksies tot dié van heel krap.

The presence of the stone crab *Lithodes murrayi* (Fig. 1) has been reported from several parts of the Southern Hemisphere and over a wide range of depths. In the literature, areas and depths of occurrence are cited as being: Prince Edward Islands (567 m) — Henderson (1888); Macquarie Island (120 m) — Hale (1941); southern New Zealand (209 m) — Yaldwyn and Dawson (1970); Crozet Islands (35 — 180 m) — Arnaud and Do-Chi (1977); Chile (70 m) — Campodonico and Guzman (1972); east coast of South Africa (600 — 810 m) — Kensley (1977); west coast of southern Africa (800 m) — Kensley (1980). This report is the first record of commercial exploitation of the species.

Since 1979 there has been an active red-crab (*Geryon quinquedens*) fishery off the continental shelf of northern South West Africa/Namibia (Beyers and Wilke 1980). Small numbers of stone crab have occasionally formed an insignificant by-catch of vessels fishing for red crab, but only very infrequently have they been processed.

During August and September 1979, the Sea Fisheries Institute and a company based in South West Africa already engaged in the red-crab fishery conducted a joint survey with the aim of establishing the southern extent of the red-crab grounds. In the course of this survey, an area (Grid Area 233, Fig. 2) yielding large catches of *L. murrayi* was discovered in a depth range of 600 — 700 m.

The fishing company conducted further experimental fishing during September and October 1979 and established that *L. murrayi* occurred in high numbers over a substantial area. This led to the transferring by the company of one of their two crab-fishing vessels from the red-crab grounds in northern S.W.A. to these stone-crab grounds off central and southern S.W.A.

The F.V. *Cormorano*, of 611 g.r.t., began intensive commercial fishing for *L. murrayi* in November 1979. The fishery was short-lived, however, and it terminated in early April 1980 when the catch per unit effort (C.P.U.E.) dropped to uneconomic levels. It is the object of this report to examine the decline in C.P.U.E. and the change in the population size structure of *L. murrayi* as a result of exploitation.

METHODS

Experimental fishing

Prior to the commencement of commercial fishing, an attempt was made by the industry to gain some idea of the extent of the *L. murrayi* grounds. During September and October 1979, experimental fishing was conducted in a total of 23 different grid areas (Fig. 2). In February 1980, after commercial



Fig. 1: The stone crab *Lithodes murrayi*

fishing operations had commenced, experimental fishing was also conducted in three other grid areas.

The experimental fishing during September and October was conducted with longlines of 50 traps set at different depths, 88,4 per cent of which were set between 500 and 700 m (*L. murrayi* has seldom been caught in large quantities outside these depths off S.W.A.). The lines were set for varying periods of time, the majority being hauled after 12—24 hours. No line was set for longer than 28 hours. Experimental catches in February were made with standard commercial longline gear.

Commercial fishing

The method of fishing for *L. murrayi* was similar to

that described for *G. quinquedens* (Beyers and Wilke 1980). The catcher vessel had several longlines, each of which usually had about 300 crab pots spaced approximately 10 fathoms (18 m) apart. The time that the pots were left in the water varied widely, but it was usually between 24 and 48 hours. On most working days three, or occasionally four, longlines were hauled, the catch was processed and the traps were reset.

The industry considered it uneconomic to process small crabs, despite the absence of an imposed minimum legal size limit. Samples of the commercial catch showed that, in general, crabs larger than 10,2 cm L_s , measured from the tip of the most anterior spine to the posterior edge of the cephalothorax (Fig. 3), were retained. The rest of the catch was returned live to the sea.

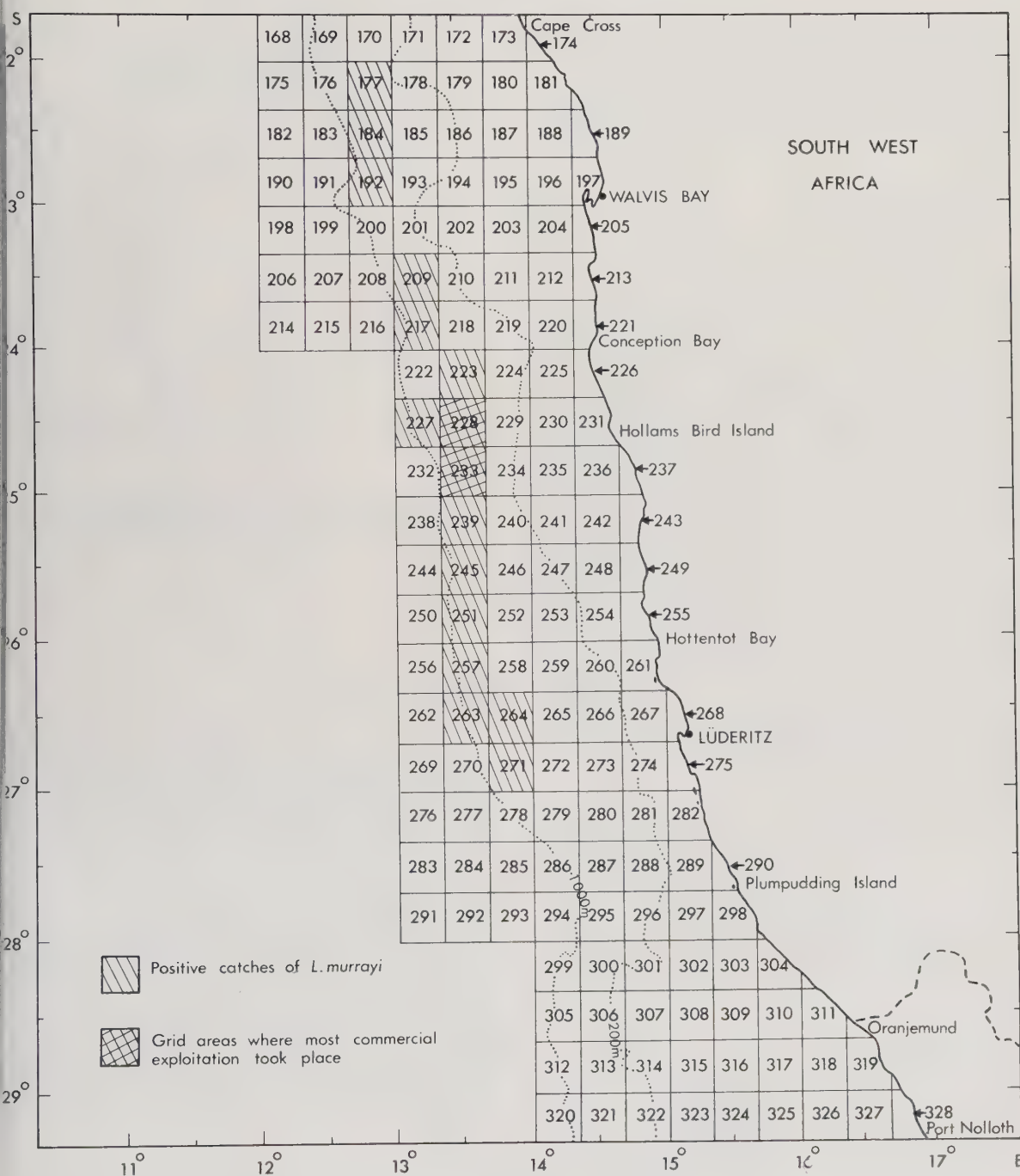


Fig. 2: Areas of positive catches of *Lithodes murrayi*, as identified on the standard trawl grid

The crabs retained were processed by removing the carapace and then splitting the body down the centre of the thoracic sternum into two halves. Each half, termed a section by the industry and referred to as such in this report, was cleaned of the gills and any attached viscera by means of rotating nylon brushes.

Analysis of statistics

The F.V. *Cormorano* was accompanied by a representative of the Sea Fisheries Institute for approximately ten days of each of the first three months of 1980. Random samples of 200–300 crabs per longline set were analysed on board. All the animals sampled were sexed and measured with calipers to the nearest millimetre. Measurements were initially (January and February) taken from the anterior tip of the rostrum to the posterior edge of the cephalothorax, denoted L_r (Fig. 3). From March onwards, L_s (Fig. 3) was measured instead, because the rostrum was frequently found to be broken, making it impossible to determine L_r accurately.

Commercial catch statistics were supplied to the Institute as kilogramme uncooked, sectioned crab per longline of traps. In each case the exact number of traps, the time (in hours) of submersion, the grid area (see Fig. 2) and the depth were given.

Some of the early catch statistics for experimental fishing (September and October 1979) were supplied as kilogramme whole mass per longline per hour. In order to standardize the data, all catch statistics have been converted to kilogramme whole mass per trap per 24 hours.

During commercial operations, the crab traps were usually retrieved after 24–48 hours. Occasionally however, they were left for much longer periods before being retrieved, and the effort was then disproportionate to the catch. For this reason, whenever the traps were left for longer than an arbitrarily chosen 60-hour period before being retrieved, the data have been disregarded unless otherwise stated.

Research fishing

During September 1979 and October 1980, two longlines of 20 and 50 traps each were set on the commercial grounds in Grid Area 233 (see Fig. 2). Although the number of crabs caught in these two settings was small ($N = 225$ and $N = 199$), they nevertheless provided an opportunity to examine the population size structure before and after commercial fishing had taken place.

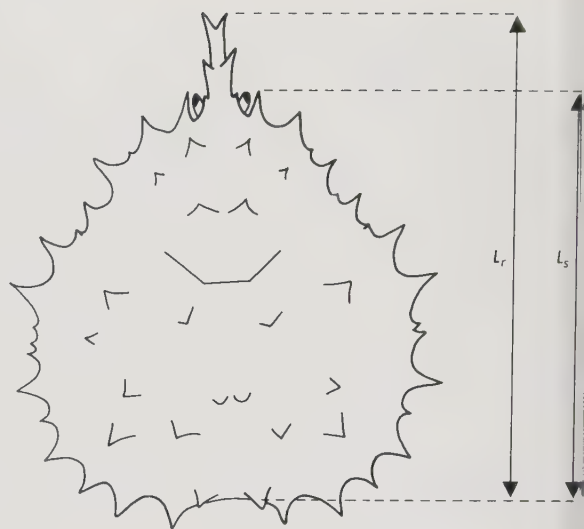


Fig. 3: A generalized *Lithodes murrayi* carapace, showing the anatomical features used for taking length measurements

RESULTS

Experimental fishing

The results of experimental fishing are given in Table I. No substantial catches were made further south than 26°20'S (Grid Areas 257 and 258). Trap C.P.U.E. values to the north showed that, although low values were recorded as far north as 22°S (Grid Area 177), no notable catches (C.P.U.E. greater than 1 kg whole mass per trap per 24 hours) were made north of 24°S, except in Grid Area 192.

The suggested lesser abundance of *L. murrayi* north of 24°S has been substantiated by the results of several trawling surveys (Sea Fisheries Institute, unpublished data), which have been conducted between southern latitudes 19 and 22° and in depths of 400–800 m. These trawl surveys have never produced more than occasional single specimens of *L. murrayi* north of 21°S, though south of this latitude substantial numbers have been trawled in depths of 400–600 m.

Morphometrics

For the purpose of converting all data to a standard format, certain morphometric relationships

Table I: Catch per unit effort of commercial-sized *Lithodes murrayi* in various grid areas caught during experimental fishing, September/October 1979 and February 1980

Grid area	Effort (trap-days)	Catch (kg whole mass)	C.P.U.E. (kg whole mass per trap-day)
†177	769,0	203,4	0,26
†184	1 383,0	1 016,9	0,74
192	148,9	325,6	2,19
209	160,2	128,2	0,80
217	69,8	68,8	0,99
†223	608,0	1 423,7	2,34
227	92,1	127,4	1,38
228	365,5	1 989,2	5,44
233	157,3	1 265,7	8,05
239	83,3	135,8	1,63
245	1 136,1	5 800,0	5,11
251	180,6	618,5	3,42
257	34,2	220,4	6,44
258	20,0	142,3	7,12
263	174,9	75,3	0,43
264	11,9	0	0
270	62,4	0	0
271	87,6	3,7	0,04
295	29,7	0	0
299	32,5	0	0
300	152,1	0	0
305	33,3	0	0
306	28,7	0	0
312	239,5	0	0
313	181,0	0	0
321	96,8	0	0

Fished in February 1980 only

All other grid areas were fished in Sep./Oct. 1979 only

had to be calculated. The first of these, the conversion from L_r to L_s , was necessary because of a change in sampling technique. The second, the conversion of length to whole mass, required other regressions to be calculated before the conversion factor could be obtained.

The relationship between section mass and whole mass was calculated for male crabs 10,2 cm L_s and larger. Similar data for female *L. murrayi* (Melville-Smith unpublished data, have shown that their section to whole mass relationship differed from that of the males. However, it was considered that, because females only constitute about 9 per cent of the commercial catch by number and less than 5 per cent by weight (based on commercial samples taken in January, February and March 1980), the use of the male conversion factors on the combined data would not bias the results unduly.

The crabs used to calculate these relationships were all undamaged animals (i.e. with no appendages lost or in the process of regeneration) in the intermoult hard-shell state. They were frozen immediately after capture and were thawed in the laboratory before the measurements were made. All measure-

Table II: Equations expressing the relationship between carapace length L_r and carapace length L_s for the sexes singly and combined

Sex	Regression equation	N	Correlation coefficient r
Male	$y = 0,9582 x - 0,7525$	89	0,9968
Female	$y = 0,9850 x - 1,0313$	59	0,9870
Both sexes	$y = 0,9630 x - 0,8077$	148	0,9950

ments of mass were made on an electronic balance to the nearest gramme.

Relationship between carapace length (L_r) and carapace length (L_s) — Values of carapace length L_r were regressed against carapace length L_s in order to convert data on size composition expressed as L_r to L_s , the carapace measurement used in this report.

Females of 6,7 — 11,6 cm L_s and males between 6,1 and 14,0 cm L_s were used to calculate the regression equations presented in Table II. The equations for male and female crabs were statistically tested for significance of difference of slope and elevation (Snedecor and Cochran 1967). No significant difference was found (slope $F = 1,64$, $P > 0,1$; elevation $F = 0$, $P > 0,25$), and the data for the two sexes could therefore be combined (Table II).

Relationship between carapace length (L_s) and whole wet mass — The relationship between carapace length L_s and whole mass was calculated from 79 male crabs of carapace length varying between 10,2 and 16,0 cm (i.e. all of commercial size). The relationship was

$$y = 0,3225 x^{3,0981},$$

where y = whole mass (g)

x = carapace length L_s (cm).

The correlation coefficient (r) was 0,9590.

Relationship between carapace length (L_s) and section wet mass — The same 79 crabs were processed in the laboratory to the section product in a similar manner to that used on board the commercial catcher. The relationship between carapace length and section mass was established as

$$y = 0,0373 x^{3,7603},$$

where y = section mass (g)

x = carapace length L_s (cm).

The correlation coefficient (r) was 0,9546.

Relationship between section mass and whole mass — From the previous two relationships it was established that the wet section mass constituted a

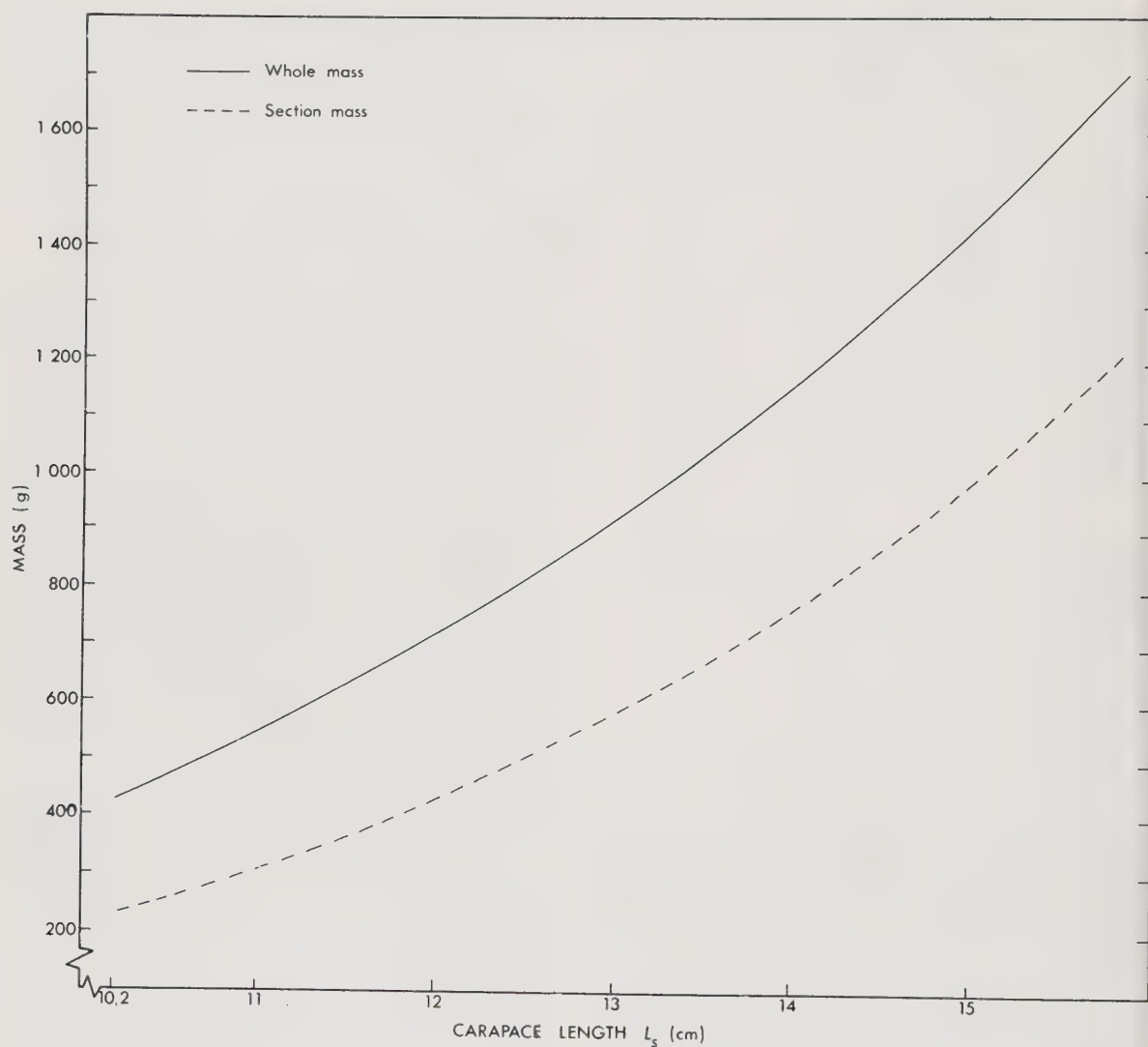


Fig. 4: Relationship between whole and sectioned crab mass and carapace length of *Lithodes murrayi* (males ≥ 10.2 cm)

greater percentage of the whole mass in the larger commercially exploited crabs than in the smaller sizes (Fig. 4). The percentage varied from 53.8 per cent in a 10.2-cm crab to 72.5 per cent in a 16.0-cm specimen.

The mean carapace size of commercially exploited male crabs was 11.7 cm in January — April 1980, the period from which commercial catch composition data are available. For a crab of this size, the section mass constitutes 59 per cent of the whole mass,

according to the equations already given. A factor of 1.6949 was therefore used to convert section mass to whole mass.

Catch per unit effort

The C.P.U.E. values per grid area, taken from commercial catch statistics for the months November 1979 — April 1980, are given in Tables III and

Table III: Total commercial effort expended and estimated quantity of stone crab processed in each grid area, November 1979 - April 1980 (excluding the data from traps set longer than 60 hours)

Grid area	Effort		Estimated whole mass	
	Trap-days	Percentage	kg	Percentage
228	43 427	66,0	96 966,0	72,9
233	15 798	24,0	30 508,5	22,9
192	2 305	3,5	2 644,1	2,0
184	1 383	2,1	1 016,9	0,8
223	1 075	1,6	1 593,2	1,2
227	1 026	1,6	84,7	0,1
177	769	1,2	203,4	0,2
Total	65 783		133 016,8	

V. Occasions when the traps were left for longer than 60 hours have been excluded to avoid bias.

From the effort applied and the quantity of crab caught per grid area, and excluding all data from

traps set longer than 60 hours (Table III), it is clear that 95,8 per cent of the catch originated from two grid areas. Grid Area 228 accounted for 72,9 per cent of the catch and Grid Area 233 for the other 22,9 per cent. Although a small amount of effort was applied in other grid areas, catches were generally poor.

The combined C.P.U.E. values and fishing effort for Grid Areas 228 and 233 are presented in Figure 5. Because these two areas accounted for over 90 per cent of the total effort (Table III), their C.P.U.E. pattern is considered to be representative of that of the stone-crab fishery as a whole.

From Figure 5, it is clear that fishing effort generally increased during the period that the stock was exploited, and by March it had virtually doubled over that of November, the month in which the fishery began. By contrast, the C.P.U.E. in March was about a third of its value at commencement and was still falling. From the start of the commercial operation in November until its termination in April, the C.P.U.E. consistently declined, and at no stage was there ever a sign of recovery in any of the grid areas (Table IV).

Table IV: Grid areas fished and the corresponding C.P.U.E. for each month of commercial fishing, November 1979 - April 1980

Month	Grid area	Effort (trap-days)	Estimated section mass (kg)	Estimated whole mass (kg)	Estimated C.P.U.E. (kg whole mass per trap-day)
Nov. '79	228	8 291	16 700	28 305,0	3,41
Dec. '79	228	5 479	10 400	17 627,1	3,22
	233	4 663	8 850	15 000,0	3,22
	Total	10 142	19 250	32 627,1	3,22
Jan. '80	228	10 792	17 610	29 847,5	2,77
	233	1 878	1 950	3 305,1	1,76
	Total	12 670	19 560	33 152,6	2,62
Feb. '80	228	924	700	1 186,4	1,28
	233	7 373	6 050	10 254,2	1,39
	192	2 305	1 560	2 644,1	1,15
	223	608	840	1 423,7	2,34
	184	1 383	600	1 016,9	0,74
	177	769	120	203,4	0,26
	Total	13 362	9 870	16 728,7	1,25
Mar. '80	228	14 303	11 000	18 644,1	1,30
	233	1 884	1 150	1 949,2	1,03
	277	1 026	50	84,7	0,08
	223	213	0	0	0
	Total	17 426	12 200	20 678,0	1,19
Apr. '80	228	3 638	800	1 355,9	0,37
	223	254	100	169,5	0,67
	Total	3 892	900	1 525,4	0,39

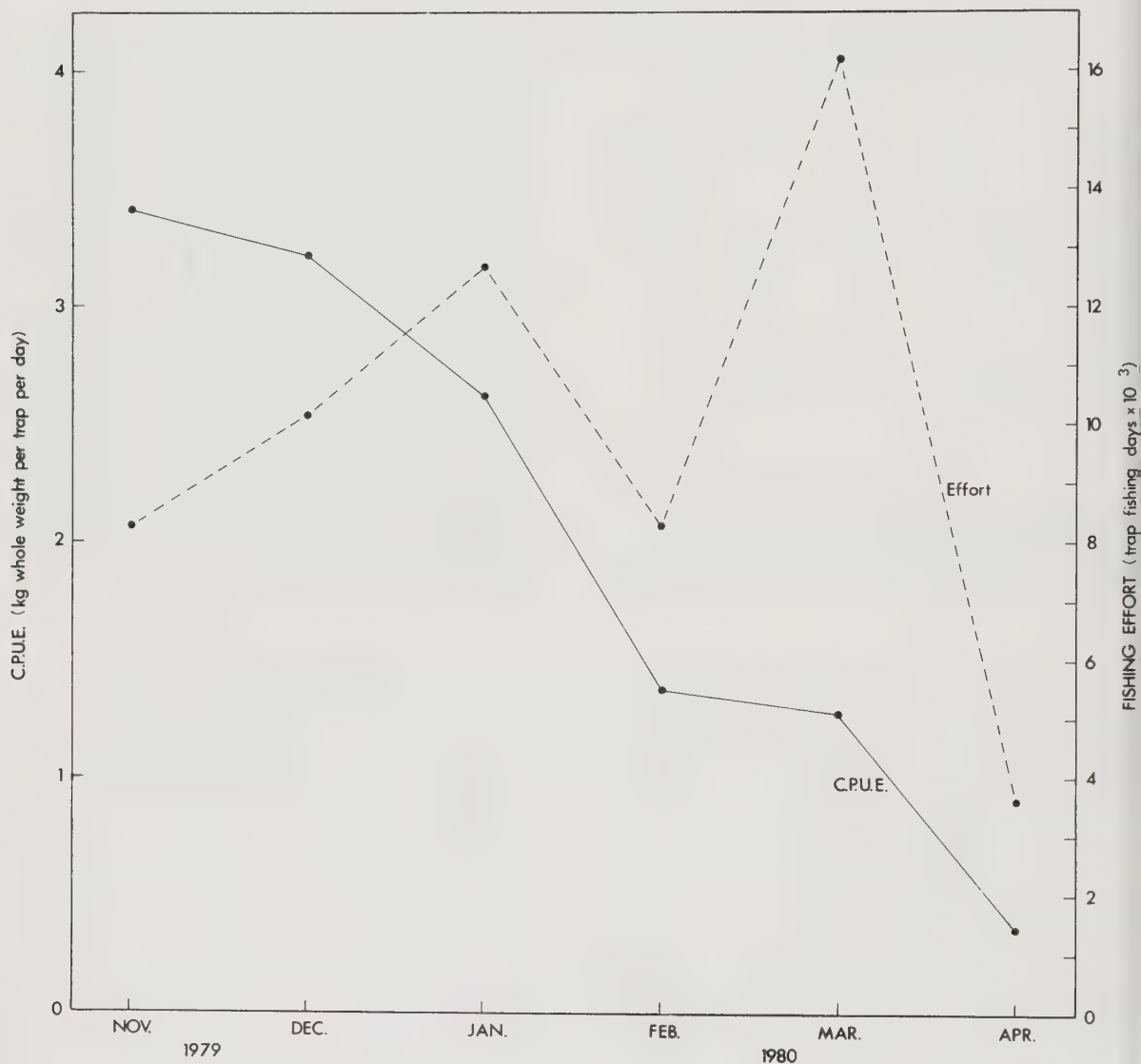


Fig. 5: Combined C.P.U.E. and fishing effort for Grid Areas 228 and 233, September 1979 — April 1980

Size composition of the catch

It was considered that, because Grid Areas 228 and 233 were regularly fished throughout the period of commercial fishing, their combined size composition data would best reflect trends.

Table V presents the size composition of the catch in five separate months. Three population mean sizes

have been calculated for the sexes: that of crabs smaller than 10.2 cm, that of those larger than 10.2 cm (i.e. commercially exploited) and that of the population as a whole.

There was little change in the mean carapace length of crabs larger or smaller than 10.2 cm. The mean size in September 1979 was slightly higher than that during the other four months, but this may be

Table V: Mean carapace length of male and female stone crab of commercial size, undersize and the whole population during five months of sampling

Sex and size class (cm)	September 1979		January 1980		February 1980		March 1980		October 1980	
	Mean L_s (cm)	N	Mean L_s (cm)	N	Mean L_s (cm)	N	Mean L_s (cm)	N	Mean L_s (cm)	N
Males $\geq 10,2$	12,0	177	11,8	1 472	11,7	2 588	11,7	537	11,8	53
Females $\geq 10,2$	10,8	7	10,6	156	10,6	65	10,7	51	10,7	12
Males $< 10,2$	9,5	16	9,1	398	8,8	855	8,7	411	8,7	62
Females $< 10,2$	9,3	25	9,1	1 099	8,8	965	8,9	512	8,7	72
All males	11,8	193	11,3	1 870	10,9	3 443	10,3	948	10,2	115
All females	9,7	32	9,3	1 255	8,9	1 030	9,0	563	9,0	84

scribed to the comparatively small sample size upon which the calculations were based. The main difference in the mean size composition of the population is apparent when all sizes are examined collectively. The mean male size declined by a total of 1,6 cm (13,6 per cent) over the fishing period, while that of females declined by 0,7 cm (7,2 per cent). The apparent excessively large decline in the mean size of females between September and January may also be attributable to the small sample size.

It appears that large male crabs (greater than 10,2 cm L_s) were being steadily fished out of the stock. Because the smaller male crabs were unaffected by fishing, their relative abundance increased proportionally. This resulted in the mean size of the population declining in sympathy with the increasing dominance of the small crabs.

The mean size of female crabs showed little decrease because the majority (about 91 per cent) were too small for commercial use and, as with small male crabs, they were returned live to the sea.

Sex ratio

The sex ratios, determined for each commercial longline set, showed no consistent depth or area trends as have been observed for *L. murrayi* caught in waters off the Crozet Islands (Arnaud and Do-Chi 1977). Male : female sex ratios recorded during commercial sampling varied between 31,9 : 68,1 and 97,4 : 2,6.

Sex ratios per size class calculated from samples of commercial catches made in Grid Area 228 are presented separately for each month of the period January — March 1980 in Figure 6 and for the three months combined in Table VI.

In the smaller size classes ($\leq 9,0$ — 9,9 cm) the sex ratio was approximately 1:1. In size classes larger than this, males became increasingly dominant and constituted 100 per cent of the sampled population for all size classes larger than 12,0 cm (Table VI).

The analysis per month (Fig. 6) shows the January catch to have had a much lower percentage of males in the small size classes than either February or March. This fact could indicate that the males were moulting, and were hence less catchable, during January. They would then have been early postmoult in February and March, and as such would have been particularly catchable having effectively starved over the moulting period. Conversely, the January sample may reflect the true sex ratio, and the relative dearth of females in February and March may have been the result of females starting to moult during those months. More data are required to substantiate either of those postulates.

DISCUSSION

The fact that male *L. murrayi* attained a larger size than females suggests that the sexes have a differential growth rate, as is the case in many decapod crusta-

Table VI: Sex ratios per size class in Grid Area 228, January — March 1980

Size class (cm)	Sex ratio	Sample size N
	male : female	
5,0 - 5,9	52,4 : 47,6	21
6,0 - 6,9	44,7 : 55,3	103
7,0 - 7,9	50,1 : 49,9	411
8,0 - 8,9	46,2 : 53,8	782
9,0 - 9,9	44,8 : 55,2	1 178
10,0 - 10,9	77,5 : 22,5	1 274
11,0 - 11,9	97,8 : 2,2	1 300
12,0 - 12,9	100 : 0	900
13,0 - 13,9	100 : 0	314
14,0 - 14,9	100 : 0	61
15,0 - 15,9	100 : 0	3
Total	73,9 : 26,1	6 347

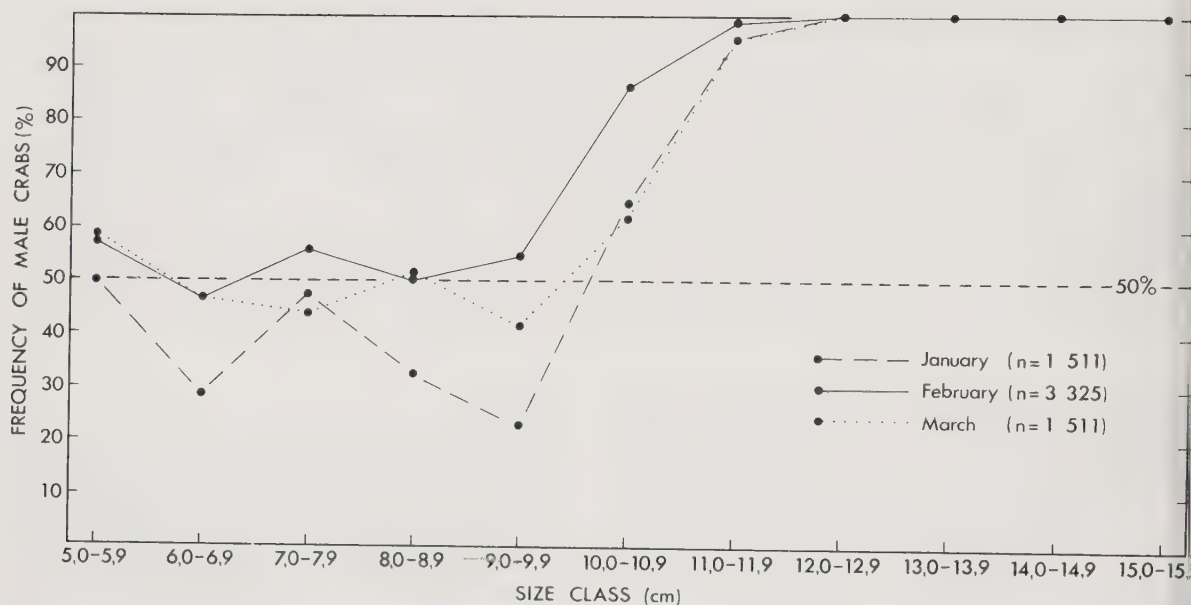


Fig. 6: Sex ratios per size class from samples of commercial catches in Area 228, January — March 1980

ceans, including the related lithodid *Paralithodes camtschatica*, the Alaskan king crab (Hoopes and Karinen 1972). This being the case, and assuming an equal sex ratio at spawning, one would expect females to have dominated the smaller size classes. However, this did not transpire during the period sampled (Table VI).

Several reasons could account for the apparent anomaly. The original assumption of a 1:1 sex ratio at spawning may be incorrect. Also, there may be different mortality rates for the sexes, or one of the sexes may have been at a stage in the moult cycle rendering it either particularly easy or difficult to catch. It is necessary to obtain catch composition data from a full year before a more positive assumption can be made in this regard.

C.P.U.E. can provide an indication of the changes in stock density with fishing, provided there is no natural biologically linked cycle of catchability. Such cycles can be linked to, amongst other things, seasonal environmental changes or an annual moult.

If the catchability of the *L. murrayi* stock remained relatively constant over the period of commercial fishing, then some indication of fluctuation in stock density caused by fishing can be gauged from the drop in C.P.U.E. over this period.

The C.P.U.E. in Grid Area 228 was 3.41 at the start of commercial fishing in November 1979. When fishing ceased in April 1980, the C.P.U.E. had dropped to 0.37 (Table IV). This is a nine-fold decrease, which suggests that the abundance of crabs larger than 10.2 cm in this area at the termination of fishing was only about 11 per cent of that at the start of fishing, all other factors remaining constant.

Stone crab appear to be largely confined to a hypothetical corridor between the 500- and 700-m depth contours over a distance of approximately 300 nautical miles. The densities of the crabs, based on C.P.U.E., were moderately high over most of the corridor (Table I), but not sufficiently high for a fishery to be commercially viable. Densities were apparently extremely high over the 40-mile length across Areas 228 and 233. Of the estimated 185 400 kg, being the total whole mass of *L. murrayi* landed between November 1979 and April 1980, 94.6 per cent came from these two grid areas.

It is possible that the apparent collapse of this short-lived fishery could have been avoided, and that the small *L. murrayi* stock could have been managed on a sound basis. From an economic point of view, however, the exploitation of a small continental-shelf stock such as this one poses complex problems. The fishing craft have to be of substantial size for safe

operation far out at sea, and the fishing equipment is costly because of the working depth. It is therefore obvious that there is no means of avoiding the type of large-scale effort which ships of this size need to generate in order to make them an economic proposition.

Depending on the rate of growth, this stock may gain become profitably exploitable in the future. Should this be the case, the solution to its healthy exploitation would be to manage it in conjunction with the *G. quinquedens* stock, which is at present fished on the continental shelf north of 21°S (Beyers and Wilke 1980). Because the same equipment is used to fish for both species of crab, it may be possible to restrict the level of exploitation of *L. murrayi* by diverting the bulk of effort towards the *G. quinquedens* fishery. The latter species, being more widespread and abundant, has proved to be better able to withstand exploitation.

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BIOLOGY OF THE ROCK LOBSTER *PALINURUS GILCHRISTI* WITH NOTES ON THE SOUTH AFRICAN FISHERY

D.E. POLLOCK AND C.J. AUGUSTYN

Biological characteristics of the rock lobster *Palinurus gilchristi*, which occurs over large areas of the south and south-east coast of South Africa, are examined. Size composition data from research cruises showed differences between east, central and western sectors of the fishery, with mean and modal sizes increasing from east to west. Analysis of commercial pack categories showed a decline in mean and modal sizes over the period 1974-1980, probably as a result of the impact of the fishery on the stocks. Sex ratios were examined on an areal and seasonal basis. Fifty per cent of females were sexually mature at 55-65 mm carapace length. Four developmental stages of eggs are described, and fecundity is compared with that of *Jasus lalandii*. Growth rates were found to be low, to differ significantly between the sexes, and apparently to diminish in an easterly direction. The vessels and gear used in the fishery since 1974 are discussed and catch and catch per unit effort, which have declined in each sector, examined. Some biological comparisons are made with a closely related species, *P. delagoae*, which is found off the Natal coast. Recruitment, larval drift and the productivity of the stock are discussed.

Die ondersoek behels die biologiese kenmerke van die kreef *Palinurus gilchristi*, wat oor uitgestrekte gebiede langs die suid- en suidooskus van Suid-Afrika voorkom. Gegewens oor groottesamestelling wat uit navorsingsvaarte verkry is, toon verskille aan tussen die oostelike, sentrale en westelike sektore van die vissery, met toenemende gemiddelde en modale groottes van oos na wes. Ontleding van kommersiële stertverpakkingskategorieë dui op 'n afname in gemiddelde en modale groottes gedurende die tydperk 1974-1980, wat vermoedelik deur die uitwerking van die vissery op die stapel veroorsaak is. Geslagsverhoudings is op 'n gebieds- en seisoenmatige grondslag ondersoek. Vyftig persent van die wyfies was by 'n doplengte van 55 tot 65 mm geslagsryp. Vier ontwikkelingsstadiums van eiers word beskryf, en vrugbaarheid met dié van *Jasus lalandii* vergelyk. Daar is bevind dat groeikoerse laag is, dat hulle by die geslagte aanmerklik verskil en dat hulle ooswaarts skynbaar daal. Die vaartuie en vangtuig wat sedert 1974 in die vissery gebruik word, word bespreek, en vangs en vangs per pogingseenheid, wat in elke sektor gedaal het, word ondersoek. Biologies word die spesie in enkele opsigte met 'n naverwante spesie langs die Natalse kus, *P. delagoae*, vergelyk. Rekrutering, dryfverspreiding van larwes en die produktiwiteit van die stapel word bespreek.

The rock lobster *Palinurus gilchristi* Stebbing, first described in 1900, is a known resident of southern Cape waters, being recorded occasionally in trawler catches, but never in large quantities. In 1974, commercially exploitable densities were discovered by trap-fishing on a patch of rocky ground in about 110 m of water off Port Elizabeth. Subsequently, the population has been found to extend over vast areas of rocky sea-bed near the edge of the continental shelf between Cape Agulhas in the west and Port Alfred in the east (Fig. 1). Numbers of *P. gilchristi* have been caught in traps at Rocky Bank off False Bay, but their occurrence in waters to the west of Cape Point is thought to be very rare.

Five species of *Palinurus* are recognized worldwide. They are *P. mauretanicus* Gruvel (West Africa), *P. charlestoni* Forest and Postel (Cape Verde islands), *P. elephas* Fabricius (British Isles, western Mediterranean), *P. gilchristi* Stebbing (southern Cape coast) and *P. delagoae* Barnard (east coast of southern Africa, Malagasy). Berry and Planté (1973), in a revision of *Palinurus* species in southern African waters, raised *P. delagoae* to specific rank, when previously it had been regarded

as a variety of *P. gilchristi*. *P. delagoae* is known to occur from Moma (17°S) in northern Moçambique to some 45 km south of Durban in depths from 180 to 320 m (Berry 1971, 1973), and its range does not appear to overlap with that of *P. gilchristi*.

This report describes biological findings from research surveys, and traces the development of the fishery for *P. gilchristi* from 1974 until 1980. Implications of slow growth rates and low stock density are discussed in relation to the productivity of, and expected long-term yields from, the stock.

MORPHOMETRICS

Length-weight regressions were calculated for the analysis of size composition from the commercial production of frozen tails and whole frozen rock lobster. In addition, the relationship between carapace length and the length of the second abdominal segment was calculated, so that carapace lengths could be determined if necessary from

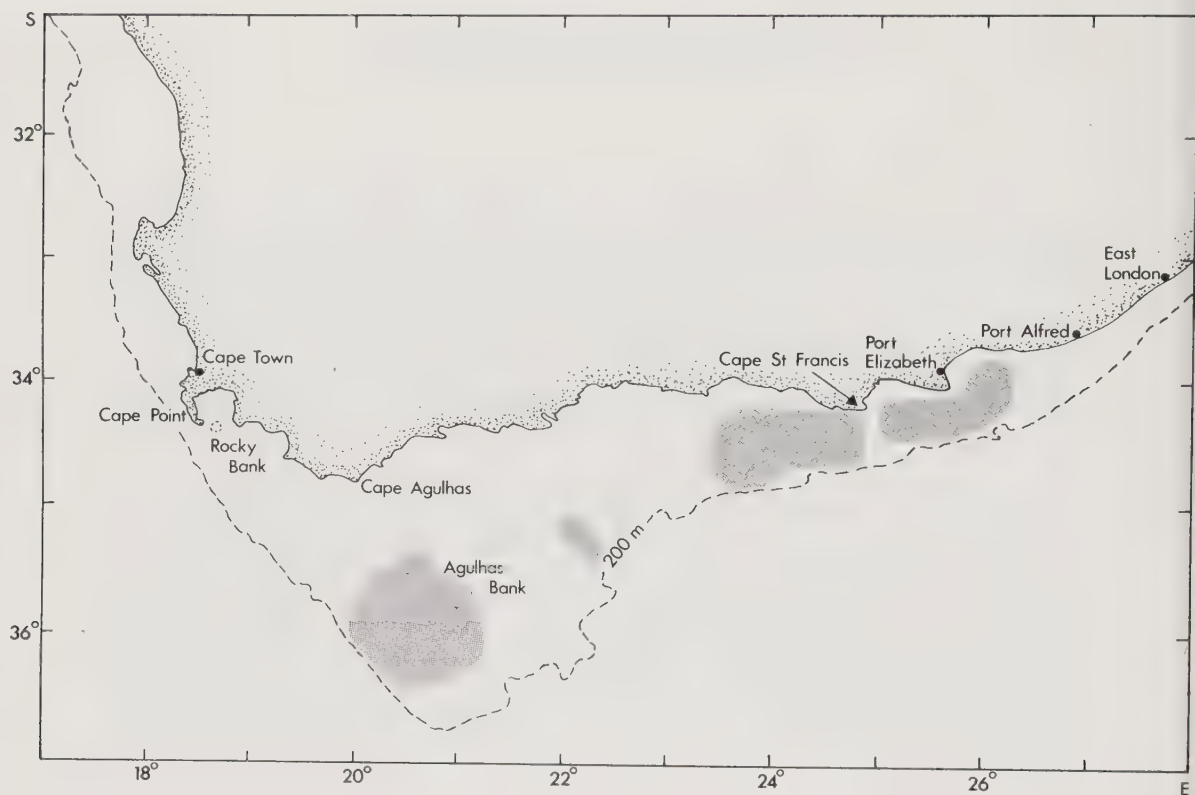


Fig. 1: Main areas fished for *Palinurus gilchristi* during the 1978/79 fishing season

samples of frozen tails.

Carapace lengths were measured dorsally from the posterior edge of the carapace to the tip of the rostral spine. Tail weight refers to the mass of the

abdomen removed by tailing the animal in the commercial manner, i.e. by removing the abdominal musculature which extends into the carapace along with the tail.

Table I: Morphometric relationships for *Palinurus gilchristi*

Relationship	Sex	Regression	n	Size range (mm carapace length)
Carapace length (mm): whole mass (g)	Males	$y = 0,0057 x^{2,5129}$	78	59 - 102
	Females	$y = 0,0034 x^{2,6400}$	63	59 - 97
	Sexes combined	$y = 0,0044 x^{2,5748}$	141	59 - 102
Carapace length (mm): tail mass (g)	Males	$y = 0,0045 x^{2,3940}$	80	59 - 102
	Females	$y = 0,0016 x^{2,6577}$	63	59 - 97
	Sexes combined	$y = 0,0028 x^{2,5144}$	143	59 - 102
Carapace length (mm): width of 2nd abdominal segment (mm)	Males	$y = 0,2379 x + 4,7841$	80	59 - 102
	Females	$y = 0,2845 x + 1,7913$	63	59 - 97

The three relationships obtained by regression analysis are given in Table I, together with sample sizes and size ranges. Females have a slightly greater whole weight than males of the same carapace length, and their tail weight is considerably greater than that of males. The length of the second abdominal segment is also slightly greater in females than in males of equal carapace length.

In general, for both sexes combined, tail weight was 49 per cent of whole weight.

SIZE COMPOSITION AND SEX RATIO

Information was obtained from a number of research survey samples (random samples of trap-

catches) and from the analysis of size categories of frozen rock-lobster products packed by the industry.

Research samples

The size composition of research trap-catches from three areas of the coast is shown in Figure 2. It is apparent that size composition (both sexes combined) differs considerably between the eastern, central and western sectors. These differences cannot be attributed to the effects of differential rates of exploitation in different geographic localities, because sampling took place before fishing appreciably altered the size composition. Initially, all commercial fishing took place in the Port Eliza-

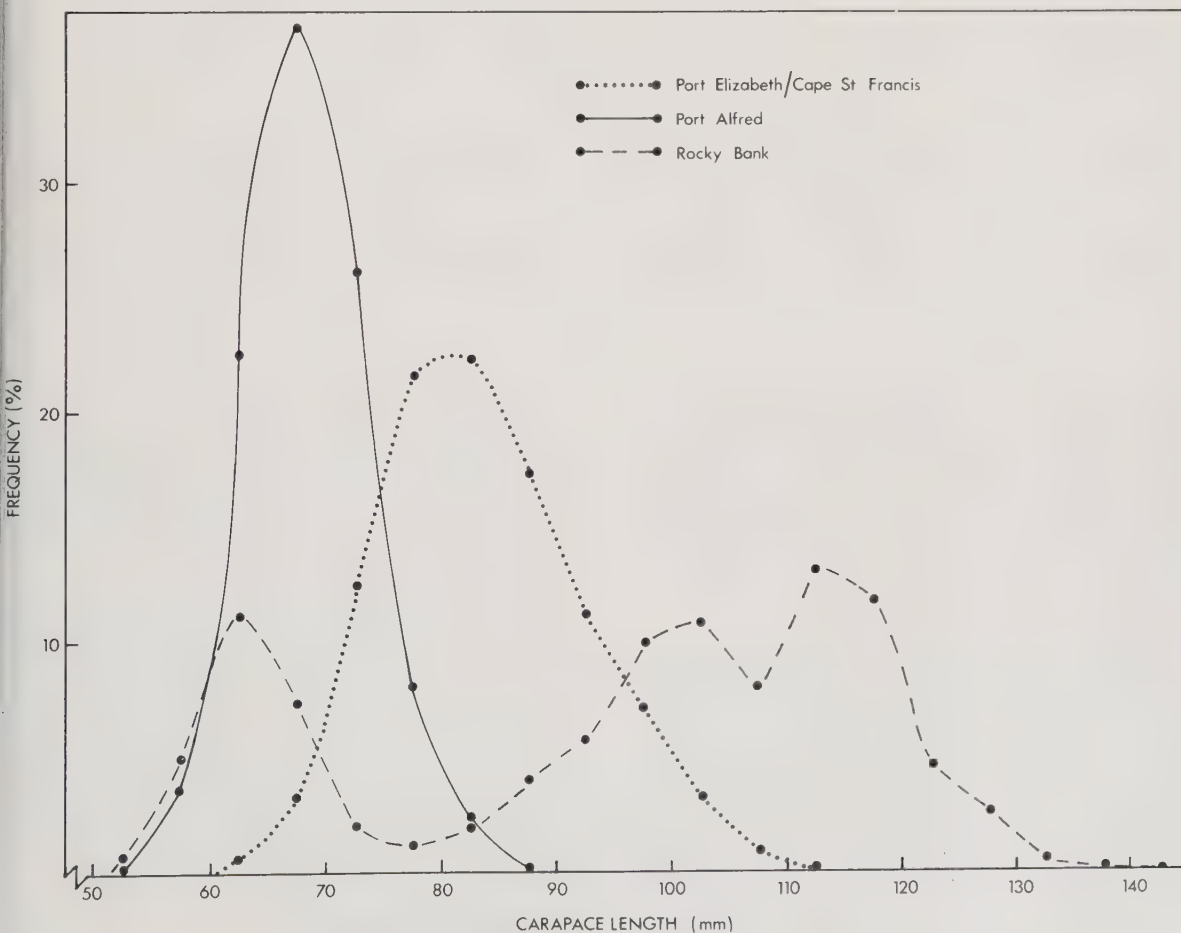


Fig. 2: Size composition of *Palinurus gilchristi* caught by traps in the eastern, central and western sectors of its range of distribution

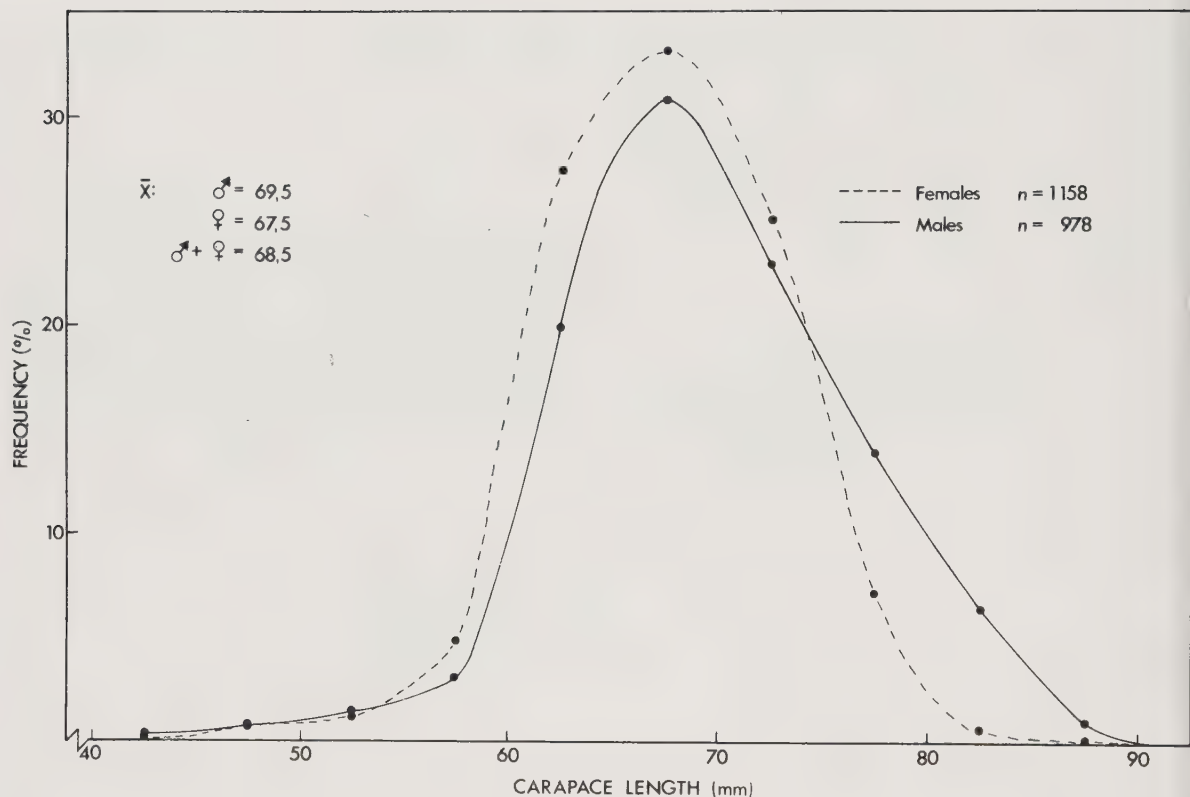


Fig. 3: Size composition of male and female *Palinurus gilchristi* at Port Alfred— all research cruises combined

beth/Cape St Francis areas of the coast (the central sector), but it spread eastwards towards Port Alfred after January 1976. From 1978 onwards, new stocks were discovered on the Agulhas Bank. Unfortunately no samples were available from the latter area, but from 1978 research samples were obtained from Rocky Bank off False Bay, further to the west.

Size frequency distributions from research cruise catches are shown in Figures 3, 4 and 5 for each sex separately in three areas of the coast. In the Port Alfred area (Fig. 3), there was little difference between the sexes, both displaying a unimodal distribution centred at about 65–70 mm carapace length. At Port Elizabeth/Cape St Francis (Fig. 4), a unimodal distribution for both sexes was again evident, but it centred at a significantly larger size (80–85 mm). At Rocky Bank (Fig. 5), size frequency distributions differed greatly from the other two areas. Both sexes displayed bimodal distributions, with a first peak at 60–65 mm, followed by a second between 100 and 120 mm carapace length.

This bimodal size distribution persisted in all samples taken during six cruises from May 1978 to June 1980. The average size in the catch in the western sector was 92 mm, compared with only 84 mm in the central sector, and some 69 mm off Port Alfred.

An interesting feature apparent from all the research trap-catches was the lack of juvenile rock lobster smaller than about 55 mm carapace length. A series of tests was made with fine-meshed traps fished together with standard-meshed traps (62 mm stretched mesh) during 1975. These tests proved conclusively that animals smaller than about 55 mm were extremely rare or altogether absent from the areas in which the adults were located. Test fishing at shallower depths close inshore (at 35, 53 and 65 m) also failed to locate juveniles.

Analysis of pack categories

As a result of large geographic variations in size

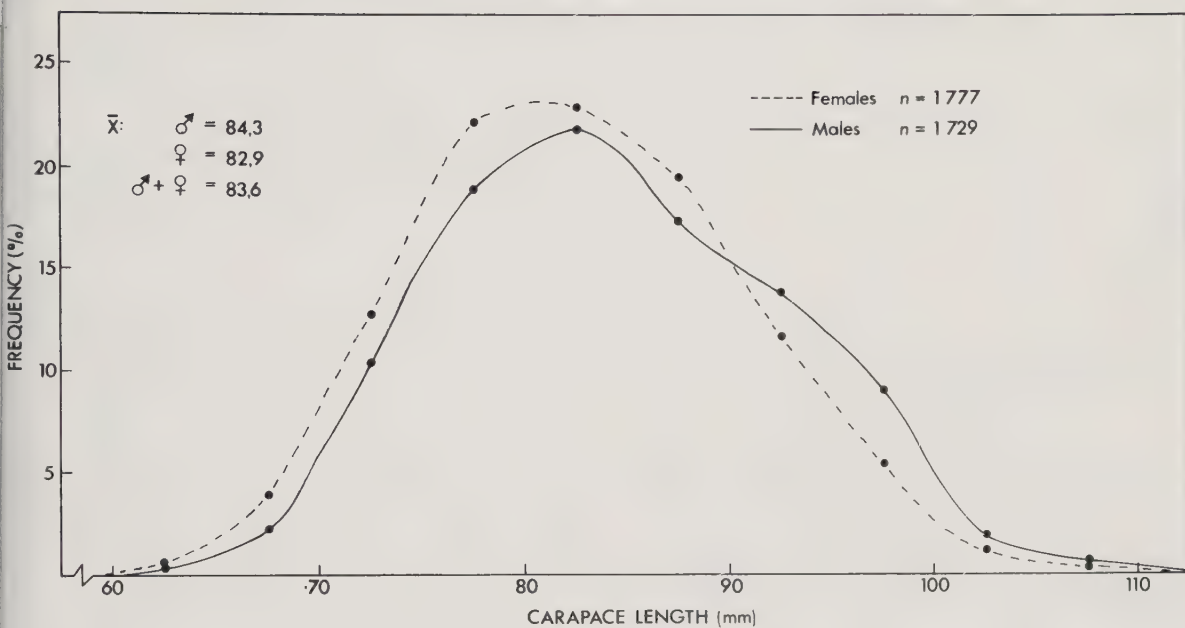


Fig. 4: Size composition of male and female *Palinurus gilchristi* at Port Elizabeth/Cape St Francis — all research cruises combined

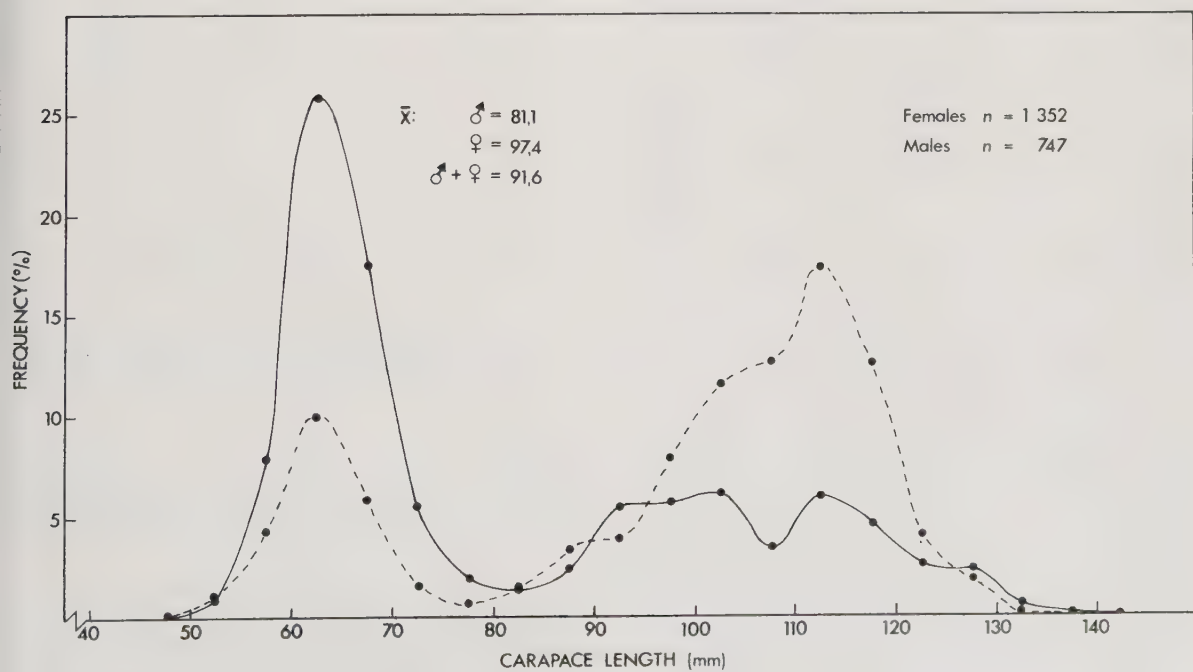


Fig. 5: Size composition of male and female *Palinurus gilchristi* at Rocky Bank — all research cruises combined

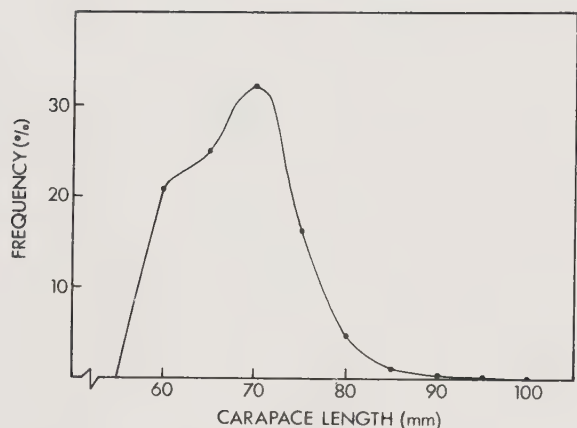


Fig. 6: Size composition at Port Alfred deduced from analysis of pack categories of frozen tails, 1977

composition, it was necessary to select information on pack categories only from vessels which had fished in one geographic area during their voyages. Catches from different areas were sometimes mixed on board, and it was not possible to separate and make use of such information.

Three distinct areas were considered: the Port Alfred area, Port Elizabeth/Cape St Francis and the Agulhas Bank, corresponding to the eastern, central and western sectors of the fishery.

Data on pack categories pertaining to vessels which had fished in specific areas were selected from some fishing companies. Most of the data available were from packs of frozen tails, which were graded by size into a number of categories. From the known number of tails in each pack category, it was possible to calculate the mean tail-weight in each category, and to convert these to mean carapace lengths. Distributions of carapace length frequency could be plotted by calculating cumulative percentage frequencies of packs and converting these to frequencies per 5-mm carapace length class by graphical methods.

Sometimes, information on size composition was only available from vessels which had split their catches into frozen tails and whole cooked frozen rock lobster. As the latter were selected from amongst the smallest sizes of rock lobster in the catch, the data for the two different types of production had to be combined. Use was then made of both regressions of length on tail weight and of length on whole weight to calculate mean carapace lengths for the different categories of tails and of whole cooked frozen rock lobsters. In the latter, allowance was made for an approximate loss of 15 per cent by weight during cooking and freezing.

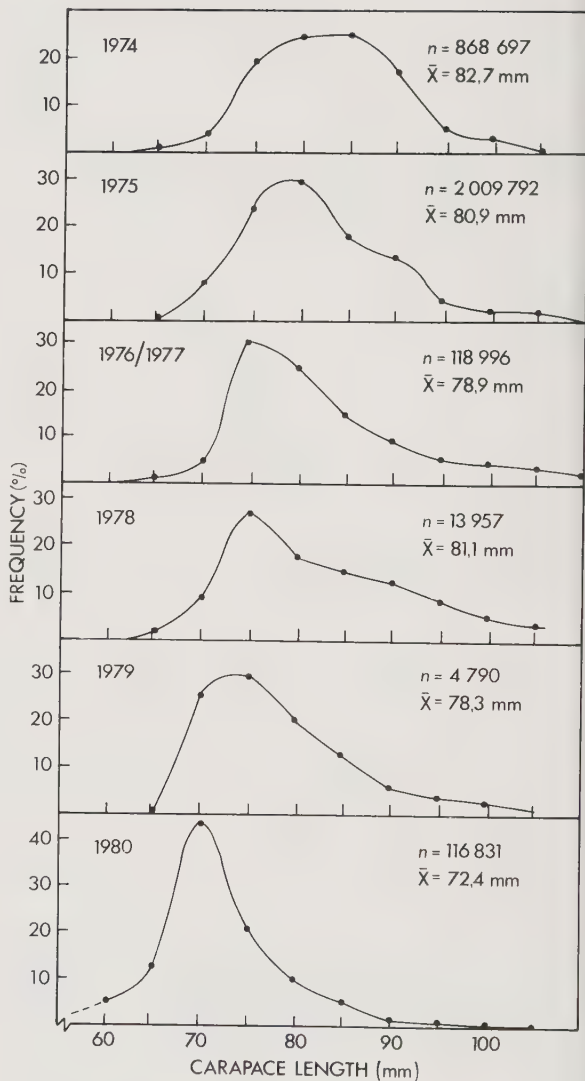


Fig. 7: Size composition at Port Elizabeth/Cape St Francis deduced from analysis of pack categories of frozen tails, 1974–1980

Cumulative frequencies were compiled for each product separately, the frequency of animals per 5-mm carapace length class was calculated, and finally the data were combined.

Eastern sector — Data on pack categories were available from only two vessels during 1977. The results, shown in Figure 6, confirm that the modal size in the catch was 65 — 70 mm, and that the size distribution was similar to that of research catches made in this area during 1976 and 1977 (Fig. 3).

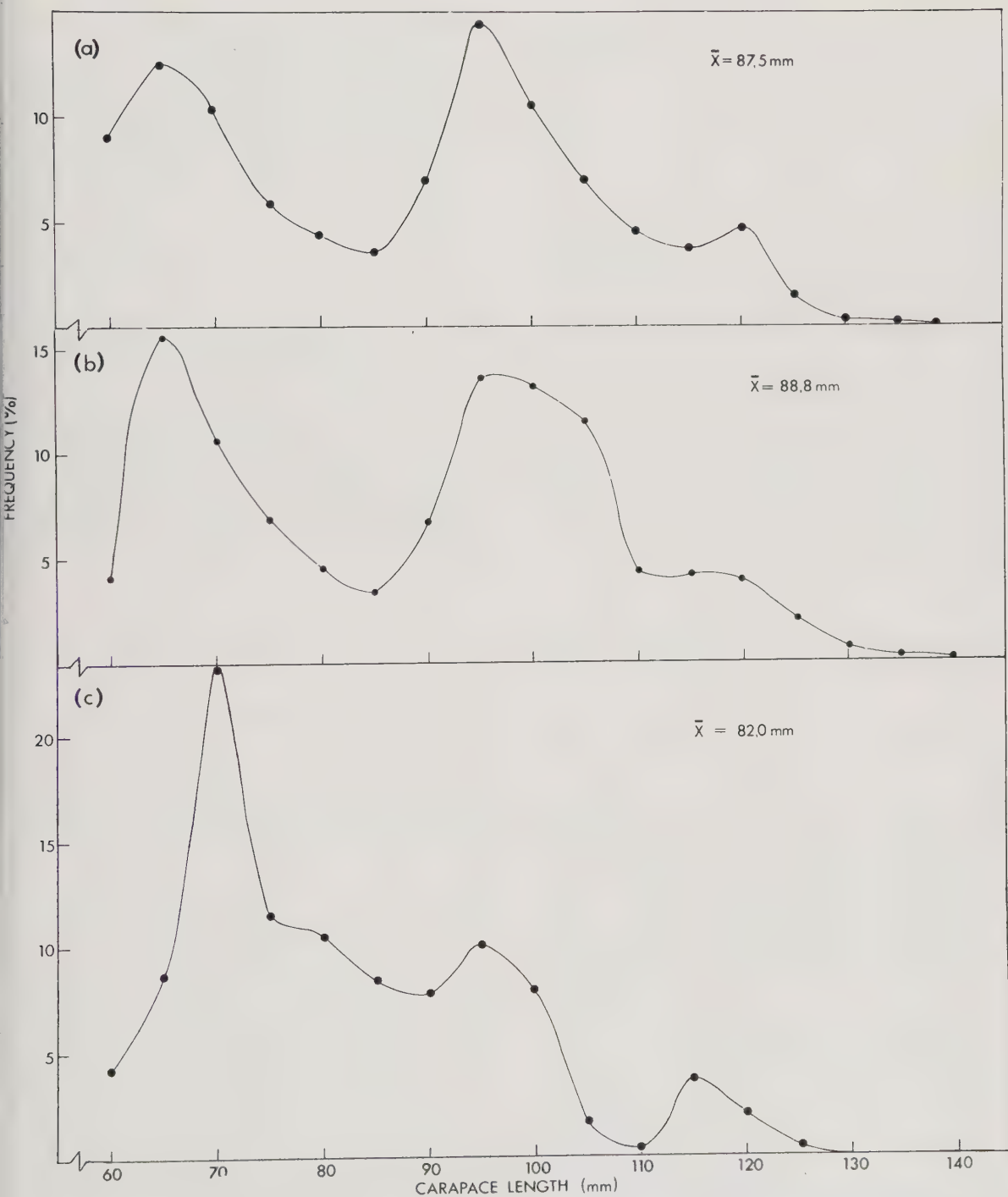


Fig. 8: Size composition in Agulhas area deduced from analysis of pack categories of a) frozen tails and whole cooked rock lobster caught by F.V. Stanley D in November/December 1980, b) similar production of F.V. Pam Arlene D in November/December 1980, (c) frozen tails caught by F.V. Southern Mariner in April 1980

Central sector — Data on pack categories collected for this area from 1974 until 1980 were available for comparison. Results are illustrated in Figure 7. There was a perceptible and consistent decline in both the average and modal sizes caught and packed during this period. The mean size packed declined from 83 mm in 1974 to 72 mm by 1980.

Western sector — Data on pack categories were available from two vessels in November/December 1978 and from one vessel in April 1980. Each catch was analysed separately, and the size composition graphs resulting from the analysis are presented for comparison in Figure 8. The curves show a remarkable degree of consistency. All are polymodal, with peaks at 65 — 70 mm, 95 mm and 115 — 120 mm carapace length. Because of the paucity of representative samples of pack categories, it was not possible to speculate on possible changes in size frequency distribution between the two years for which information was available. The size composition obtained from these pack categories was remarkably similar to that from research trap-fishing at Rocky Bank (Fig. 5).

Sex ratio

Sex ratios in research samples from the Port Elizabeth/Cape St Francis area averaged 50 males : 50 females for all size classes combined. At Port Alfred, the sex ratio differed slightly, but significantly, from parity (54 female : 46 male — $P < 0.01$). At Rocky Bank, samples showed a marked preponderance of females, the overall sex ratio being 64 females : 36 males.

In order to examine regional differences in sex ratio in more detail, the ratios in individual size classes were examined by combining all length frequency data from each area. In addition, seasonal trends in sex ratio were examined for the Port Elizabeth/Cape St Francis area, when sufficient data were available.

Table II lists sex ratios per size class for the Port Alfred region, Cape St Francis/Port Elizabeth and Rocky Bank. There are significant deviations from parity in the sex ratio. At Port Alfred and Port Elizabeth/Cape St Francis, males predominated in the largest size classes whereas, at Rocky Bank, there was a preponderance of females in the larger

Table II: Sex ratios per size class from research catches in three areas of the fishery

Size class (mm carapace length)	Port Alfred			Port Elizabeth/ Cape St Francis			Rocky Bank		
	<i>n</i>	Sex ratio ♂ : ♀	Significance	<i>n</i>	Sex ratio ♂ : ♀	Significance	<i>n</i>	Sex ratio ♂ : ♀	Significance
45 - 49							1		
50 - 54							20	1:1.9	
55 - 59	84	1:2	++				117	1:1	
60 - 64	512	1:1.6	+++	27	1:2		329	1:0.7	++
65 - 69	684	1:1.3	++	176	1:1.8	+++	210	1:0.6	+++
70 - 74	513	1:1.3	++	676	1:1.4	+++	62	1:0.5	+
75 - 79	219	1:0.6	+++	1 203	1:1.3	+++	23	1:0.6	
80 - 84	70	1:0.1	+++	1 354	1:1.1		29	1:1.9	
85 - 89	11	1:0.1	++	1 073	1:1.3	+++	61	1:2.6	+++
90 - 94				740	1:1		91	1:1.3	
95 - 99				412	1:0.7	+++	148	1:2.5	+++
100 - 104				133	1:0.3	+++	202	1:3.4	+++
105 - 109				24	1:0.5		197	1:6.9	+++
110 - 114							279	1:5.2	+++
115 - 119							204	1:5.0	+++
120 - 124							75	1:3.0	+++
125 - 129							42	1:1.5	
130 - 134							5	1:0.3	
135 - 139							3	1:2	
140 - 144							1		

+ Significant ($P < 0.05$)

++ Highly significant ($P < 0.01$)

+++ Very highly significant ($P < 0.001$)

Table III: Percentage of females in research catches from the Port Elizabeth/Cape St Francis area, November 1974 - September 1975

Month	Percentage females	Sample size (♂ + ♀)
November 1974	63	1 903
January 1975	53	1 403
March 1975	48	877
May 1975	46	1 271
June 1975	33	504
July 1975	34	852
September 1975	38	752

size classes.

Seasonal variations in sex ratio are shown in Table III for the Port Elizabeth/Cape St Francis grounds, where 12 fishing stations were occupied routinely every second month from November 1974 to September 1975. Table III shows that the percentage of females in the samples declined in June and July, but increased again towards the end of the year. At this stage it is not possible to speculate as to whether these fluctuations were caused by low availability of females or increased availability of males during the winter months.

REPRODUCTIVE BIOLOGY

Size of females at sexual maturity

The presence of ovigerous setae on the pleopods was used as a gauge of sexual maturity. The percentages of females with ovigerous setae in different size classes, for samples from Port Alfred, Port Elizabeth/Cape St Francis and Rocky Bank,

Table IV: Frequency per size class of females with ovigerous setae at three localities (sample sizes in brackets)

Size class (mm carapace length)	Percentage of females with ovigerous setae		
	Port Alfred	Port Elizabeth/Cape St Francis	Rocky Bank
45 - 49	9 (11)	- (0)	- (0)
50 - 54	11 (18)	- (0)	0 (7)
55 - 59	85 (60)	100 (4)	4 (27)
60 - 64	99 (382)*	100 (25)*	31 (71)*
65 - 69	100 (467)*	100 (117)*	62 (50)*
70 - 74		100 (357)	93 (14)

* Tested for significance of difference between size classes and areas

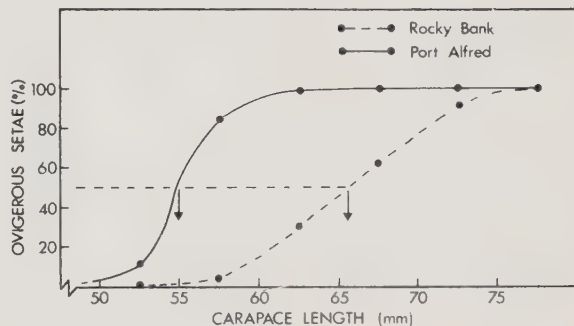


Fig. 9: Percentage of females with ovigerous setae per 5-mm size class

are compared in Table IV. The data show that the onset of sexual maturity occurs at a relatively large size at Rocky Bank in comparison with the other two areas. This becomes more apparent when the data are plotted (Fig. 9). The length at 50-per-cent maturity for Rocky Bank females is about 65 mm, whereas it is only 55 mm at Port Alfred ($P < 0,001$). No sexually immature females were found in any of the samples from Port Elizabeth/Cape St Francis, so it is not possible to determine whether the size at 50-per-cent maturity differed between Port Alfred and Port Elizabeth/Cape St Francis.

Females in berry

Eggs from females in different stages of berry were examined microscopically to determine whether clearly differentiated stages of egg development could be distinguished. Concurrently, diameters of about 10 eggs per specimen were measured, and mean egg diameters were obtained from a number of specimens. Four different stages could be distinguished, but it was not possible to determine the duration of each stage, nor of the whole period of egg-bearing.

Stage 1 — In this stage the eggs were bright orange, had no eye-spots and the yolk filled more than 90 per cent of the volume. The mean egg diameter, calculated from 18 rock lobsters, was 0,8 mm.

Stage 2 — The eggs were orange and the eye-spots were just visible through a hand-lens. The yolk filled about two-thirds of the egg. The mean egg diameter, determined from nine rock lobsters, was 0,9 mm.

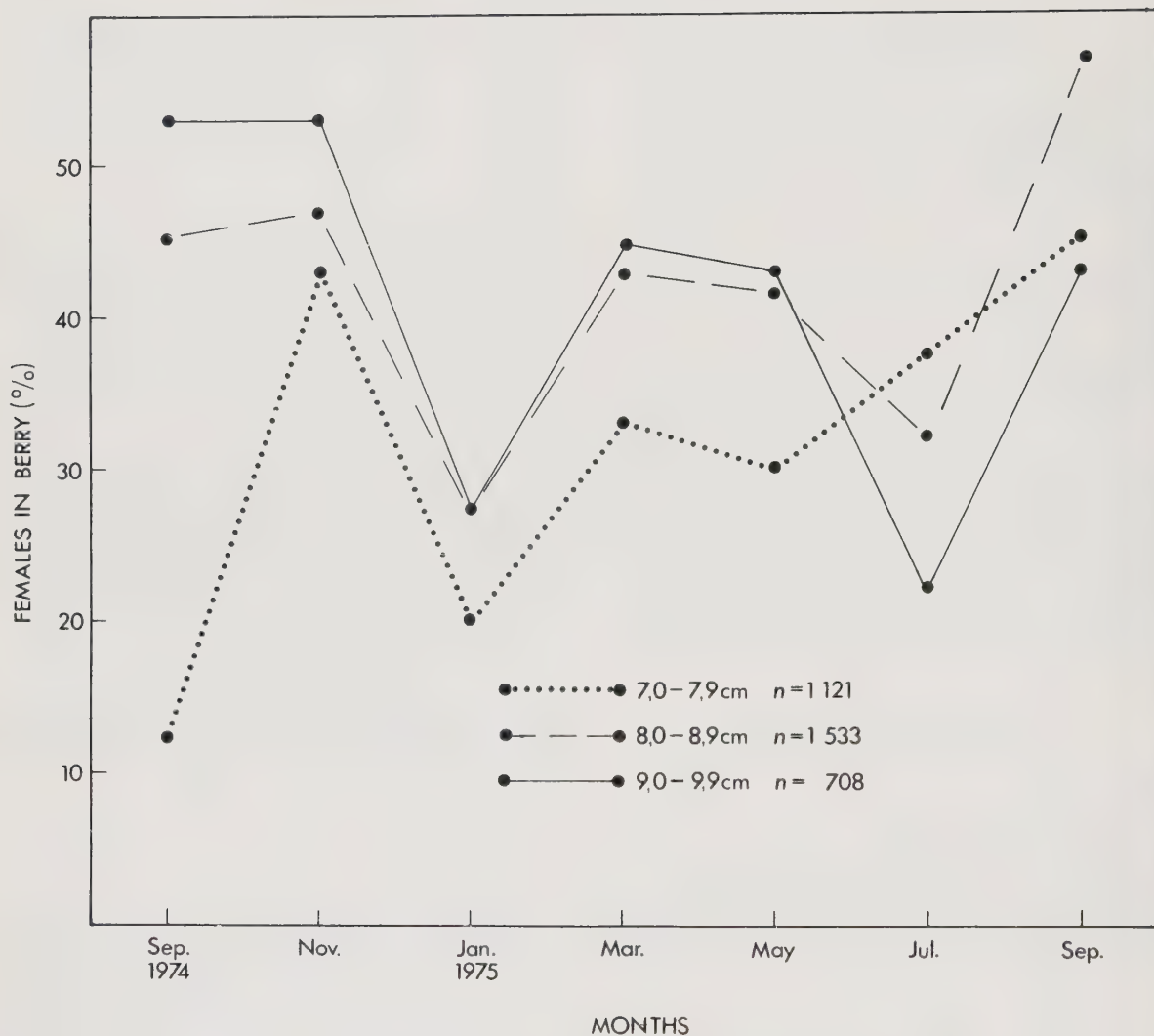


Fig. 10: Percentage of females in berry per size class, 1974—1975

Stage 3 — The eggs were orange and the eye-spots were clearly visible. The mean egg diameter (1.0 mm) was determined from 23 specimens.

Stage 4 — The eggs were brown, the eye-spots were obvious, and there was little or no yolk left. The mean egg diameter was 1.0 mm and was derived from two rock lobsters.

Silberbauer (1971) noted a similar increase in diameter of the eggs of the West Coast rock lobster *Jasus lalandii*, and she suggested that it was caused

by increased uptake of water during development.

The percentage of females in berry, split into three 10-mm size classes, is plotted on Figure 10 for the Port Elizabeth/Cape St Francis grounds during the period September 1974 — September 1975. All three size classes displayed similar fluctuations, with the highest proportion in berry during September—November, and again from March to May. Unlike the West Coast rock lobster *Jasus lalandii*, which has a well defined seasonal berry cycle, between 25 and 46 per cent of female *P.*

gilchristi were found in berry throughout the year.

Fecundity

Egg counts from 16 females in berry, ranging from 67 to 101 mm in carapace length, were used to calculate a regression of number of eggs against carapace length. Egg count was related linearly to carapace length by the equation

$$y = 1\,778x - 73\,717,$$

where y is the number of eggs and x is the carapace length in millimetres.

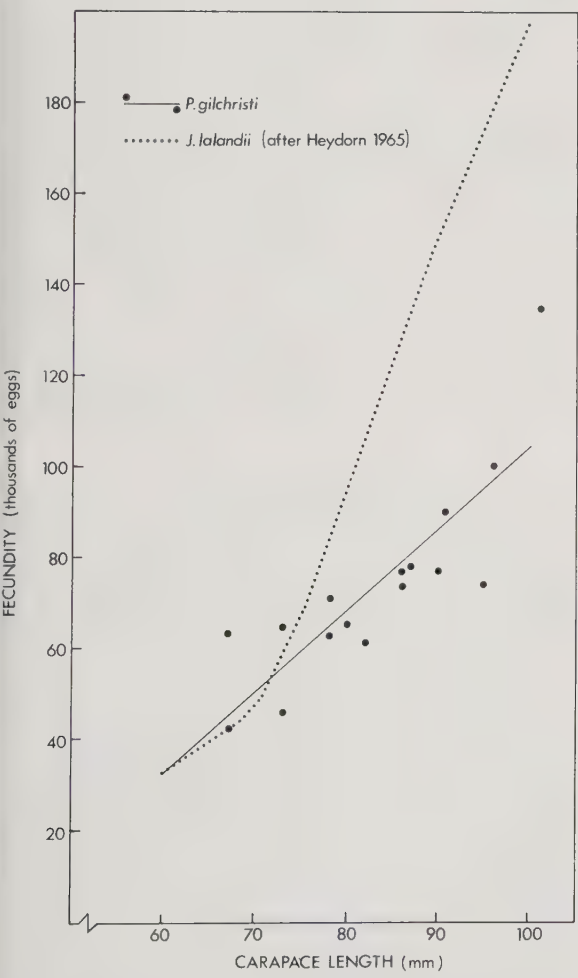


Fig. 11: Relationship between carapace length and the number of eggs carried on the abdomen

The relationship is displayed in Figure 11, together with the regression for *Jasus lalandii* calculated by Heydorn (1965). At first glance it would appear that the fecundity of *P. gilchristi* is very much lower than that of *J. lalandii*, at least for sizes larger than 80 mm carapace length. However, it should be borne in mind that, whereas *J. lalandii*, is known to produce only one brood of eggs each year (Newman and Pollock 1974), the frequency of spawning of *P. gilchristi* is not yet known. If the latter species produces more than one batch of eggs per year, its fecundity relative to that of *J. lalandii* will be much higher than indicated.

Fertilization

White, jelly-like spermatophoric masses were observed on the sterna of several captured female specimens. This suggests that fertilization in *P. gilchristi* is probably external, although a detailed examination of the spermatophoric mass was not made.

GROWTH RATES

The exoskeletons of *P. gilchristi* were usually clean and free from encrusting marine growth upon capture so that it was not possible to distinguish between recently moulted specimens and those in late inter-moult stages by examination of the shells. In addition, shells were generally rather flexible under finger pressure, and again it was not possible to identify impending moults or recently moulted animals by monitoring the shell firmness. It is well known that crustaceans in soft-shelled condition do not normally feed and hence do not enter baited traps. It was, therefore, not possible to determine whether there were peak periods of moulting for either of the sexes, nor could annual moult frequency be deduced.

Despite these drawbacks, valuable information about annual growth increments was obtained from tag-recapture experiments. Several thousand animals were tagged between 1974 and 1978 during research trips to the Port Elizabeth/Cape St Francis and Port Alfred areas. In addition, a total of 1 624 animals was tagged at Rocky Bank between May 1978 and June 1980. FT-2 dart-tags were used initially, inserted between the second and third abdominal segments. At Rocky Bank, an anchor tag was also used, inserted dorsally between carapace and abdomen. After one or more moults had taken place, the FT-2 dart-tag left a clearly visible raised lip on the shell at

Table V: Mean annual growth increments for the Port Alfred area

Size class (mm carapace length)	Males			Females		
	Mean annual increment (mm)	Standard deviation	Sample size	Mean annual increment (mm)	Standard deviation	Sample size
60 - 69	1,70	0,62	13	1,26	0,54	20
70 - 79	1,41	0,59	18	0,66	0,52	15

Mean for both sexes, all sizes: $1,25 \pm 0,67$ mm

the point of insertion. Although the total number of tags returned was too small to be used for estimation of stock sizes, several moulted animals were returned after periods varying from 6 months to 4 years.

Port Alfred area

Mean annual increments for 31 males and 35 females are shown in Table V for two size classes of 10 mm. Analysis of variance showed that growth rates differed significantly between both size classes ($P < 0,05$) and sexes ($P < 0,01$). Mean annual increments of males were larger than those of females, and increments declined with increasing carapace length.

Port Elizabeth/Cape St Francis area

Only nine tagged animals which had moulted were returned from this area. One had been at large for 4 years. Because of the limited number of observations, annual increments were combined for both sexes, and a mean annual growth of 3,0 mm (standard deviation 1,34 mm) was obtained for animals ranging from 71 to 93 mm carapace length.

This growth rate is considerably higher than that recorded for males and females at Port Alfred (mean annual growth 1,25 mm, standard deviation 0,67 mm) and differed at the 1-per-cent level of significance. It would therefore appear that growth rates in the Port Elizabeth/Cape St Francis area are significantly higher than those further east, though the data are acknowledged to be somewhat limited. The differences in mean and maximum sizes of animals caught from these two areas could, therefore, be to a large extent the result of differential growth rates.

Western area

Unfortunately, no tagging could be conducted on

the Agulhas Bank, but growth increments were available from 13 moulted specimens which were tagged and recaptured at Rocky Bank after intervals ranging from 9 months to 2 years (Table VI).

A noticeable feature is the extremely small increments (often zero) in the larger size classes, compared with a comparatively rapid growth rate in the 60 — 69 mm size class. As discussed earlier, most of the rock lobsters caught at Rocky Bank were large, presumably old animals, and their growth rates would be expected to be slow. On the other hand, the growth of the small males (Table VI) appears to be considerably more rapid than that of males of the same size in the Port Alfred area (Table V).

At this stage, preliminary observations suggest that growth increments of *P. gilchristi* (and presumably growth rates) tend to diminish in an eastward direction concomitant with a progressive decline in mean and maximum carapace length of the catch.

HYDROLOGY

Measurements of temperature, salinity and oxygen content were made during seven cruises to the Cape St Francis/Port Elizabeth ground between July

Table VI: Annual growth increments at Rocky Bank

Size class (mm carapace length)	Annual increment (mm)	
	Males	Females
60 - 69	4 mm, 6 mm, 5 mm	—
70 - 79	—	—
80 - 89	—	—
90 - 99	1 mm, 0 mm, 2 mm	—
100 - 109	1 mm	0 mm, 0 mm, 0 mm, 0,25 mm
110 - 119	—	0 mm, 1 mm
120 - 129	—	0 mm

— No observation

1974 and September 1975. Surface water temperatures varied from 17 to 23°C, and surface salinities from 35,2 to 35,3‰. Near-bottom temperatures at about 110 m were very much cooler, ranging from about 9 to 11°C, with salinities of 34,8 — 34,9‰. Dissolved oxygen values near the bottom varied between 3,7 and 4,5 ml · l⁻¹.

According to Darbyshire (1964), the continental shelf in the Port Elizabeth region is dominated by two water masses — the warm Agulhas Current, flowing westwards in the upper layers, and Central Water beneath with much lower temperatures. He characterized Central Water as having a temperature range of 6—16°C with salinities of 34,5—35,5‰. The Agulhas Current varies seasonally in strength, the greatest flow being experienced during April (approximately 50 cm·s⁻¹). This current is characterized by temperatures in excess of 17°C, and salinities greater than 35,5‰.

It is evident from the hydrological measurements made during the present programme that the benthos near the shelf-edge is influenced by Central Water only, so that *P. gilchristi* lives in a cold-water environment, not dissimilar to that of *Jasus lalandii* off the Cape west coast.

THE FISHERY

Vessels and gear

Vessels in this fishery range from 20 to 100 m long, many of them being ex-trawlers adapted for trap-fishing. Adverse sea and weather conditions near the edge of the continental shelf preclude operations by smaller boats.

In 1974, when vessels first began operating off Port Elizabeth, the traps used were large, side-entry rectangular steel-framed traps, covered with polyethylene netting of 60-mm stretched mesh. These were set on single buoyed lines, as in the rock-lobster fishery for *J. lalandii* off the Cape west coast.

The fleet rapidly converted to the longline method of fishing, using series of traps on a longline buoyed at each end. Loss of traps and longlines occurred frequently, and by the end of 1974 nearly all vessels had changed to cheaper plastic traps, many more of which could be attached to the longlines. These barrel-shaped kavel traps had a single top entrance and, like the rectangular traps, were baited with fish.

The larger vessels began to use up to 150 traps per longline, and were able to fish over 1 000 traps each day. Traps were normally set for 24 hours before hauling and resetting.

The total number of vessels actively engaged in the fishery grew from 12 in 1974 to 33 in 1976, but thereafter declined gradually as yields became less lucrative. By 1980, only 18 vessels were left actively fishing and a further six vessels withdrew in 1981.

The depths fished and the optimum depths for *P. gilchristi* appear to vary somewhat from area to area, but they generally lie between 90 and 170 m.

Effort and catch per unit effort (C.P.U.E.)

Catch and effort statistics were obtained from the logbooks of most vessels which operated actively, and the total catch was derived from factory production records.

As a result of the change in the type of trap used after 1974, it was necessary to standardize effort in terms of kavel trap-hauls. Because rock lobster were normally tailed and packed on board, C.P.U.E. was calculated in terms of kilogramme tail-weight per kavel trap-haul. During research cruises, comparison of 743 rectangular trap-hauls made concurrently with 2 430 kavel trap-hauls showed that a rectangular trap caught, on average, 1,8 times as many rock lobsters as a kavel type. C.P.U.E. results for 1974 (when rectangular traps were in use) were adjusted accordingly.

Figure 12 illustrates trends in total catch and total effort from 1974 to 1980. Effort increased in 1975 with the advent of eight foreign vessels (the grounds were outside South African fishing limits), but these vessels were obliged to withdraw in 1976. The species was then recognized as part of the group of sedentary species of the continental shelf which therefore belonged to South Africa alone.

After the withdrawal of foreign fishing vessels, effort again increased gradually until 1977/78, without a concomitant increase in catch, and thereafter both catch and effort declined. Steeply rising fuel prices forced more and more vessels to withdraw from the fishery.

The three geographic sectors of the fishery mentioned earlier came under exploitation at different periods, and catches were boosted as previously unexploited stocks were discovered in new areas. Table VII shows trends in catch, effort and C.P.U.E. in the three sectors from 1974 onwards. C.P.U.E. has clearly declined in each of the sectors since exploitation began, showing that the fishery has made a significant impact on the stocks in each area. A large reduction in fishing effort took place during 1979/80, when many of the vessels diverted to fishing for tuna during an exceptional run of yellowfin tuna *Thunnus albacares*.

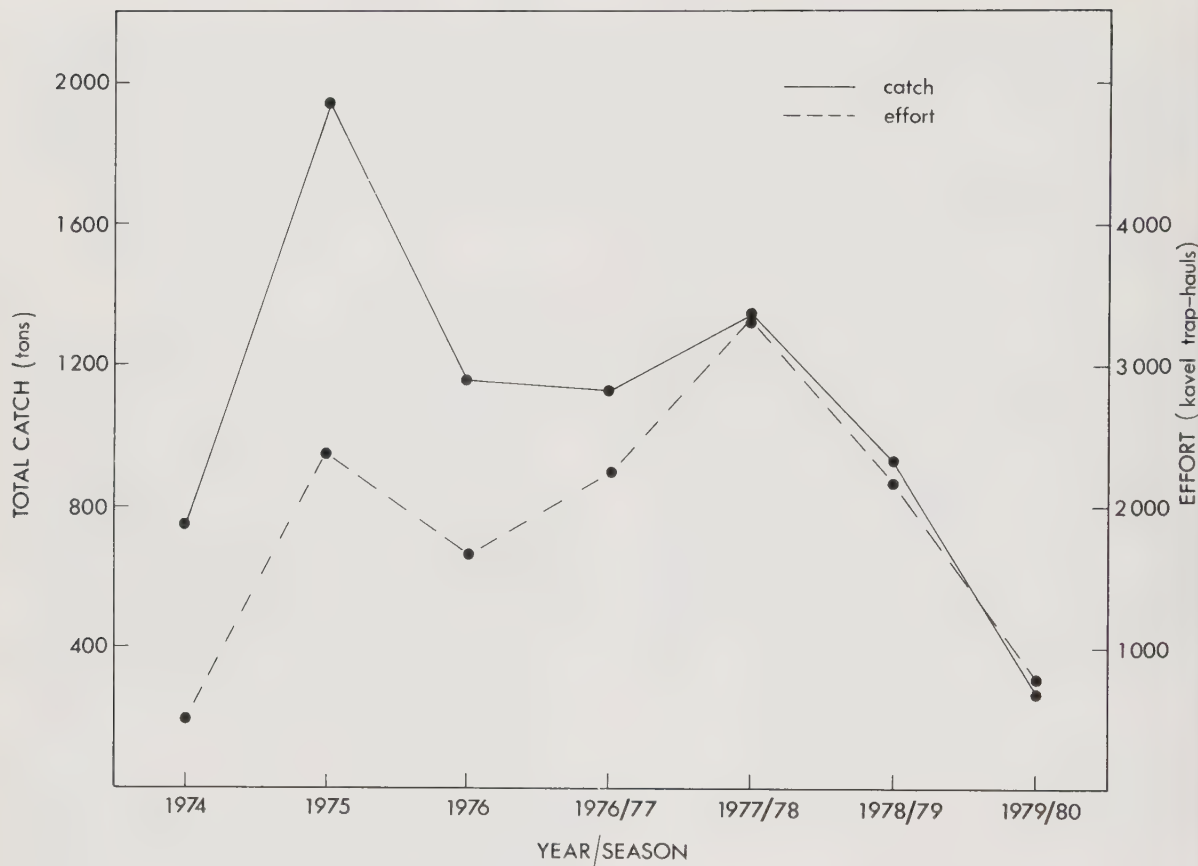


Fig. 12: Catch and effort in the South Coast rock-lobster fishery, 1974—1979/80

DISCUSSION

Because this is the first report to describe the biology and population characteristics of *P. gilchristi*, it is of interest to compare findings with those on the closely related *P. delagoae*, a species which has been the subject of various reports by Berry (1971, 1973, 1974).

Very close morphological similarities exist between *P. gilchristi* and *P. delagoae*. The most obvious morphological difference appears to be that in *P. gilchristi* the entire dorsal region of the cephalothorax is covered with small setae between the spines, whereas in *P. delagoae* the precervical region has no setae and is shiny (Berry and Planté 1973). Differences in the supraorbital horns cannot be used as a distinguishing character, because wide variation is

found within both species.

The reproductive biology of the two species is similar. Berry (1973) estimated a size at 50-per-cent maturity for female *P. delagoae* (based on the frequency of egg-bearing) of 70 mm, which is not much greater than the range of 55 — 65 mm noted here for *P. gilchristi* (based on the presence of ovigerous setae). Egg production appears to be greater in *P. delagoae*. According to Berry (1974), *P. delagoae* females of 80 mm carapace length produce in the region of 78 400 eggs (calculated from the linear regression of number of eggs against carapace length) compared with about 68 500 eggs for *P. gilchristi* of the same size. Fertilization in both species is external, by means of a gelatinous spermatophore deposited by the male on the sternum of the female (Berry and Heydorn 1970).

Berry (1973) suggested that female *P. delagoae*

Table VII: Catch, effort and catch per unit effort for three sectors of the South Coast rock-lobster fishing grounds, 1974 - 1979/80

Period/fishing season	Catch (tons tail mass)	Effort (thousands of trap-hauls)	C.P.U.E. (kg tail mass per trap-haul)
<i>Agulhas Bank</i>			
1974	—	—	—
1975	—	—	—
1976 Jan.-Jun.	—	—	—
1976/77 Oct.-May	—	—	—
1977/78 Oct.-Jun.	75	322	0,23
1978/79 Nov.-Jun.	241	1 100	0,22
1979/80 Nov.-Jun.	88	462	0,19
<i>Port Elizabeth/Cape St Francis</i>			
1974	185	132	0,78
1975	247	605	0,41
1976 Jan.-Jun.	89	264	0,33
1976/77 Oct.-May	466	1 850	0,25
1977/78 Oct.-Jun.	414	2 173	0,19
1978/79 Nov.-Jun.	179	961	0,19
1979/80 Nov.-Jun.	45	245	0,18
<i>Port Alfred area</i>			
1974	—	—	—
1975	—	—	—
1976 Jan.-Jun.	24	57	0,42
1976/77 Oct.-May	87	353	0,25
1977/78 Oct.-Jun.	171	785	0,22
1978/79 Nov.-Jun.	6	41	0,15
1979/80 Nov.-Jun.	3	15	0,18

— No fishing

breed once a year, and he found very few ovigerous females between May and November of the single year in which his sampling took place. His field data, confirmed to some extent by observations on captive animals, suggested an incubation period of about 6 months. Examination of moult stages in *P. delagoae* captured by trawling also led him to conclude that sexually mature animals moult once annually. It is not possible, at this stage, to comment on either moulting or breeding frequency in *P. gilchristi*, because no clear indications were apparent from the samples from research cruises examined during this study.

The two species appear to differ in their selection of habitat. *P. delagoae* occurs on extensive muddy areas of sea-bed off Natal and Moçambique (Berry 1971) where they are captured by means of bottom trawls. *P. gilchristi*, on the other hand, is generally found on rocky bottom off the southern and south-eastern Cape coast, where trawling is not possible. This factor delayed the discovery of commercially exploitable stocks of *P. gilchristi* until 1974, when

traps were set in deep-water rocky areas off Port Elizabeth for the first time.

It is quite surprising that the two species appear to be effectively separated geographically. The *P. delagoae* population lies upstream from *P. gilchristi*, beneath a southward-flowing current which would be expected to carry planktonic larvae southwards into Cape waters. Of particular note is the fact that ovigerous females of *P. delagoae* are normally found on the edge of the continental slope off Natal (Berry 1973), an area overlaid by the strongly flowing Agulhas current. Berry (1974) obtained very few larvae of *P. delagoae* in a series of surface plankton hauls off Natal, and he suggested that phyllosomata of this species either occurred at greater depths, or perhaps further off shore than 165 km. He concluded that the former was the more likely explanation. Despite the fact that adult stocks of both species exhibit differing habitat preferences, Berry (1971) has indicated that bottom temperatures off Natal are 12 — 14°C, a temperature regime not dissimilar to that in areas occupied by *P. gilchristi* off the Cape (9—11°C). It is therefore unlikely that temperature close to the sea-bed is a limiting factor for *P. delagoae* which may have drifted south. It is also possible that areas may yet be discovered where the distribution of the two species overlaps, for example off the Trans-kei coast.

In view of the comments above, the mechanism(s) whereby the Cape stock of *P. gilchristi* is able to regenerate itself via larval recruitment must be questioned. If the phyllosoma larval stages of *P. gilchristi* are similar to those of other palinurid species, the duration of planktonic life can be expected to be several months. It follows that larvae released into the swift-flowing Agulhas Current could be swept great distances before metamorphosing into the actively swimming puerulus stage. The geographical distribution of *P. gilchristi* must be influenced to a large extent by the Agulhas Current. The species has not been found to occur in any numbers west of Cape Point, yet a small concentration flourishes at Rocky Bank, apparently the extreme western edge of its distribution. This fact suggests that few larvae reach waters west of Cape Point, possibly as a result of the normal retroflexion of the Agulhas Current south-west of the Cape (Lutjeharms 1981, Lutjeharms and Valentine 1981).

Very few juveniles smaller than about 50 mm carapace length were trapped on the grounds during research cruises made between 1974 and 1978, notwithstanding some additional trials with finer-meshed traps. A few juveniles with carapace lengths ranging from 17 to 44 mm have been obtained from trawler catches in 55 — 70 m of water on the inshore

sole trawling grounds off Mossel Bay, and one record of juveniles taken off Port Alfred is available from a commercial vessel fishing with fine-mesh traps in deep water. The latter were all juveniles larger than 50 mm and were taken at the outer edge of the fishing ground in about 150 m of water.

In the light of these somewhat scanty data, the question arises whether recruitment could occur from shallower areas inshore of the fishing grounds, as well as from deeper water near the edge of the continental shelf. According to Lutjeharms (1981), the core of the Agulhas Current diverges from the coast down stream of Port Elizabeth, following the continental slope. He also mentions "consistent and ever-present" shear-edge effects which push plumes of warm water into the Agulhas Bank area on the landward border of the Current. These shear-edge features apparently increase in size towards the south-west. In a recent review of coastal currents, Harris (1978), draws attention to these cyclonic vortices of the Agulhas Current which advect warm Agulhas waters across the Agulhas Bank towards the coast. Within 30 km of the coast, longshore currents commonly reverse direction, under the influence of coastal winds. Although the net frequency of longshore currents is in a westerly direction, the possibility exists that larvae could be returned by eastward shifts in current to the region between Mossel Bay and Port Elizabeth, or even further east, especially during the winter months. Figure 13, reproduced from Harris (1978), also depicts a possible mechanism whereby larvae of *P. gilchristi* could be returned via an off-shore loop of the Agulhas Current. The main body of the Agulhas Current is known to be retroflected south of the Agulhas Bank, and it appears that an intermittent loop of the Return Agulhas Current could conceivably bring larvae back to the edge of the continental shelf in the vicinity of East London.

At present, these return mechanisms are a matter of conjecture, because of the lack of detailed information on currents off the South and East Coasts and on larval behaviour. It is hoped that future oceanographic studies will better elucidate the recruitment mechanisms postulated here.

With regard to the stock itself, it is clear from both research samples and the analysis of pack categories, that size composition differs markedly between the eastern, central and western sectors of the range of distribution. These differences suggest that extensive mixing within the population does not occur, and this is borne out by the fact that all tagged animals recaptured were caught within the same areas in which they were released. The difference in size composition appears to be related to differing growth

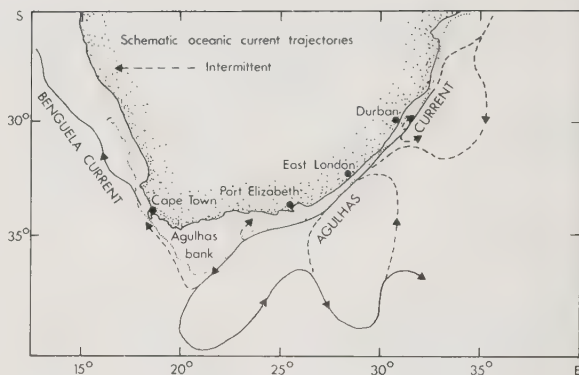


Fig. 13: Schematic trajectories of the two major ocean current systems (from Harris 1978)

rates, for it has been shown that growth rates of small animals tend to diminish towards the east. Furthermore, there are indications that the size of females at sexual maturity may be positively correlated with growth rates, because sexual maturity is attained at a smaller size off Port Elizabeth and Port Alfred than at Rocky Bank. A similar correlation has been observed by Newman and Pollock (1974) for *Jasus lalandii* on two fishing grounds off the Cape west coast.

Growth rates of rock lobsters and many other groups of marine organisms have often been found to be related to food supply, so that growth is largely determined by the relative densities of predator and prey. The relatively small growth increments of *P. gilchristi* in the eastern sector suggests that food availability may be more limited there than further west.

Although almost nothing is yet known of fishing and natural mortality rates of *P. gilchristi*, sufficient information on growth rates and stock density is available to make possible an objective generalization about the overall productivity of the stock, and of its exploitation potential. The species has a growth rate which varies geographically, yet is extremely slow. Increments in the 80–89 mm size class appear to be about 1–3 mm per annum, compared with increments in the West Coast rock lobster *Jasus lalandii* of 3–7 mm in the same size class. The fishery for *J. lalandii* is a long-established and intensive one, but it is based on a stock of high density supported by rapid recruitment rates. At present, average C.P.U.E. values for traps used on the West Coast commonly range between 50 and 75 animals (all sizes) per square trap. Catch rates of *P. gilchristi*, even after only a very short period of exploitation, do not exceed 1.0 rock

lobster per kavel trap-haul, equivalent to 1,8 rock lobsters per square trap. If it is assumed that both species of rock lobster are equally attracted towards baited traps, i.e. that the catchability of both species is identical, then it would appear that C.P.U.E., and hence stock density, of *P. gilchristi* is some 30 — 40 times lower than that of *Jasus lalandii*. Therefore, although the area of sea-bed inhabited by *P. gilchristi* is very large and some new stocks may yet be found, the low stock density combined with extremely slow growth rates gives strong reason to expect that the long-term yield from this resource will be small. Indeed, if fishing costs continue to rise without a concomitant rise in the price of rock-lobster products, it is likely that more vessels will withdraw from the fishery, leading to eventual stabilization at a much lower level of yield than at present.

The low stock density of *P. gilchristi* may be directly related to a slow rate of recruitment. As mentioned earlier, juveniles less than 50 mm carapace length were apparently not present on the fishing grounds, and it must be assumed that animals move onto the fishing grounds gradually at a size of about 60 mm, from either shallower or deeper waters. Berry (1973), who examined trawl catches of the closely related species *Palinurus delagoae* in Natal waters, also noted a lack of juveniles smaller than about 60 mm within the depth range trawled (180—324 m). A limited number of observations from deeper waters (up to 400 m) led him to believe that juveniles occur at greater depths than the mainly adult stock, and that recruitment takes place as maturing animals move from deeper to shallower waters. This would imply that the final larval stages of *P. delagoae* settle on the continental slope off Natal. How the larvae are retained within this system is yet another problem which at present defies explanation.

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DIET OF PREDATORY AND REEF FISH IN FALSE BAY AND POSSIBLE EFFECTS OF PELAGIC PURSE-SEINING ON THEIR FOOD SUPPLY

C.S. DE V. NEPGEN

There have been allegations that the activities of the purse-seine boats fishing for pelagic fish in False Bay were the main cause for the decline in availability of line-fish, especially predators, in that area. According to the complaints the purse-seiners not only remove the food supply of the line-fish but also catch a great number of them. A research programme was therefore initiated in which stomach contents of line-fish in False Bay were analysed and landings of pelagic fish caught in False Bay were examined for by-catches. A list of food items found in the stomachs of line-fish is given. The investigation indicated that pelagic fish are important as food for the predatory fish in False Bay, but not for the reef fish. It was also found that the activities of the purse-seiners fishing in the Bay were limited and that they did not have much effect on the line-fish catches. The by-catch of the purse-seiners was negligible and should have no effect on the availability of line-fish in False Bay.

Daar is beweer dat beursnetbote wat pelagiese vis in Valsbaai vang die hooforsaak van die skaarste van lynvis, veral roofvisse, in die baai is deurdat hulle nie alleen die voedselvoorraad van die lynvisse verwyder nie maar ook 'n groot aantal roof- en bankvisse as byvangste vang. 'n Navorsingsprogram is gevolglik uitgevoer waarin die pensinhoud van roof- en bankvisse in Valsbaai ontleed is en die vragte afgelaai deur beursnetbote wat vangste in Valsbaai gemaak het vir byvangste ondersoek is. 'n Lys van voedselsoorte wat in pense van lynvisse gevind is word aangegee. Die ondersoek het getoon dat die pelagiese vis 'n belangrike voedselbron vir die roofvisse in Valsbaai is maar nie vir die bankvisse nie. Daar is ook bevind dat die bedrywighede van die beursnetbote in Valsbaai maar beperk is en nie die lynvangste noemenswaardig benadeel nie. Daar is ook bevind dat die byvangste van roof- en bankvisse in die beursnetvangste so gering is dat dit geen effek op die beskikbaarheid van lynvis in Valsbaai behoort te hê nie.

False Bay is a large, U-shaped bay of over 400 square miles situated roughly between 34°05'S and 34°25'S and between 18°28'E and 18°50'E. It is open to the ocean on its southern side between Cape Point and Cape Hangklip (Fig. 1).

The bathymetry and the microrelief of False Bay were described by Mallory (1970), the physical environment by Atkins (1970a, b) and by Cram (1970) and the biology by Day (1970). The fishes of the Bay were listed by Day *et al.* (1970).

The Bay, being near Cape Town, is easily accessible to recreational and professional fishermen who use a variety of methods for the catching of fish, such as line-fishing by rock, surf and boat anglers, spear-fishing by divers, trek-fishing with beach-seines and purse-seining for pelagic fish.

Anglers, sports line-fishermen and commercial line-fishermen have been complaining for many years that there has been a drastic decline in the availability of most bony fish in False Bay. The alleged decline, in the absence of statistics, fostered growing hostility between the line-fishermen and the purse-seiners because the anglers attributed the decline, especially in the catches of predatory fish (e.g. kob, geelbek, yellowtail), to the activities of the purse-seine boats fishing in the Bay. According to the line-fishermen, the purse-seiners not only remove and break up the shoals of pelagic fish on which the predators feed, but they also catch a great number of predatory as well as

bottom-living fish during their fishing operations.

Beach-seining also takes place in the Bay and, although the catch in such nets is mainly mullet, a species which is not a major contributor to the food of predatory fish, some predatory and bottom-living fish are definitely taken.

In the absence of sufficient reliable statistics of line-fish catches in False Bay, it is difficult to ascertain what the real trends in the Bay were, and to what extent the real or supposed fluctuations in the supply of line-fish were influenced by factors such as purse-seining for pelagic shoal fish, beach seine-netting (especially for predatory fish), the catches made by anglers, the availability of food, changes in the natural environment and pollution.

This programme of research, mainly into the diet of line-caught fish, was initiated to obtain a better insight into the possible effect of the seine catches on the food supply of reef and predatory fishes.

METHODS

In order to collect as much information as possible on the effects of pelagic purse-seining on the reef and predator fish species, a programme of research was started in March 1979 and continued until April 1980.

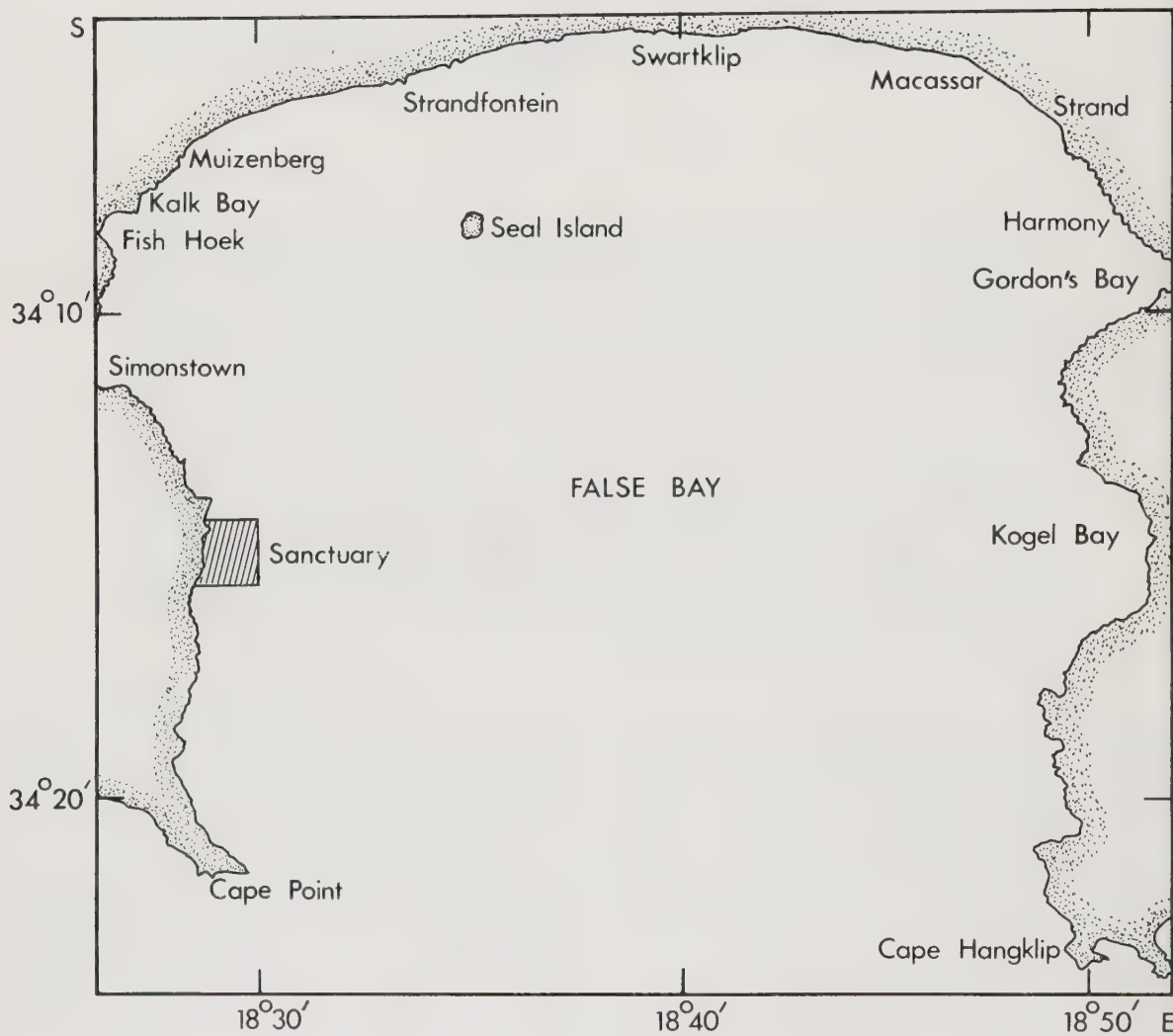


Fig. 1: False Bay

As the Institute received complaints that the purse-seiners were taking large by-catches of reef and predatory species and that, as a result of the pelagic fish catches, the food of line-fish was being removed so that less fish could find sustenance in the Bay, it was clear that these aspects should be covered by the programme of research.

Stomach contents of line-fish were collected between April 1979 and April 1980 by fishing with handlines from a research vessel. Additional samples were obtained from commercial catches landed at

Kalk Bay and Gordon's Bay, from a fish shop in the Strand, from catches made with beach-seine nets and from catches during competitions of the Western Province Rock and Surf Angling Union. Records of stomach contents of snoek, yellowtail, hottentot and silverfish (kapenaar) collected in False Bay during earlier research surveys have also been included.

Most of the kob and all geelbek stomachs were obtained from the fish shop in the Strand and came from catches made in the area between Macassar and Hangklip. All the shark stomach contents were

collected from catches made during angling competitions.

The fork and total lengths of most fish were measured before the stomachs were removed, labelled and preserved in 10-per-cent formalin or frozen in plastic bags. No fork length was taken of kob or any length of baardman, and the sharks were only weighed. Because the digestive action in the time elapsed between feeding and capture would affect the mass and the volume of the stomach contents, only the incidence of the species was utilized. In some instances the contents were so badly digested that the species involved could not be identified, and the food was assigned to the unidentifiable category.

The stomachs of all species were first divided into those containing food and those that were empty. The number of stomachs in which a particular food item occurred was then determined and that number expressed as a percentage of the number of stomachs containing food.

Snoek stomachs were obtained during every month of the year, but most were collected during July, August and December, when snoek were more available in the Bay.

Although yellowtail is regarded as a summer fish in False Bay, reasonable catches are occasionally made during other seasons. It was therefore possible to obtain yellowtail stomachs throughout the year, though most were collected during summer. Nearly all yellowtail stomachs came from fish caught in the Cape Point area and most of the remainder from Fish Hoek Bay.

Kob stomachs were only obtained between spring and the middle of autumn. Most were collected in the northern section of False Bay, in the area from Swartklip to Harmony.

Samples of geelbek stomachs were collected over a slightly shorter period than kob, i.e. between mid-spring and mid-autumn. Nearly all were caught on the eastern side of the Bay.

Elf were caught between mid-spring and the end of autumn along the northern side of the Bay.

Although mackerel are pelagic fish which form part of the purse-seine commercial catch quota and are sometimes taken in great numbers by demersal trawlers, they are also caught by anglers, especially during the summer months when large fish enter the Bay. In this survey the mackerel stomachs examined came from fish caught with handlines and that had fork lengths of more than 28 cm.

The stomachs of sharks examined were those of topes, bronze whalers and spotted gully sharks. The contents of the stomachs of the three species did not differ much, so that the results of the analyses were combined.

This survey was primarily directed to collect information on the diet of predatory fish in False Bay, but at the same time the stomachs of reef fish obtained were also analysed. However, fewer stomachs of reef fish than of predators were examined.

Landings of pelagic fish caught in False Bay by the purse-seine fleet were examined for by-catches at the factories where they were off-loaded. Because the survey started on 26 March 1979, only catches made between that date and the end of April could be examined during 1979. Only Hout Bay boats fished in the Bay during this period. The 1980 catches were inspected for by-catches during the whole period (15 January — end of April) that the purse-seine boats were allowed to fish in False Bay.

FEEDING

The stomach contents of 4 163 line-caught fish from False Bay were examined. Of these, 3 763 or 90 per cent were those of predators such as snoek (*Thyrsites atun*), yellowtail (*Seriola lalandii*), kob (*Argyrosomus hololepidotus*), geelbek (*Atractoscion aequidens*), elf (*Pomatomus saltatrix*), baardman (*Umbra capensis*), mackerel (*Scomber japonicus*) and sharks (*Carcharhinus brachyurus*, *Galeorhinus galeus*, *Mustelus nigropunctatus*). The remainder consisted of reef fish such as red roman (*Chrysoblephus laticeps*), hottentot (*Pachymetopon blochii*), white stumpnose (*Rhabdosargus globiceps*), silverfish (*Argyrozona argyrozona*), white steenbras (*Lithognathus lithognathus*), red stumpnose (*Chrysoblephus gibbiceps*), red steenbras (*Petrus rupestris*), galjoen (*Coracinus capensis*), panga (*Pterogymnus lanarius*), blue hottentot (*Pachymetopon aeneum*), musselcracker (*Cymatoceps nasutus*), zebra (*Diplodus cervinus*) blacktail (*Diplodus sargus*), John Brown (*Gymnocrotaphus curvidens*), milkfish (*Parascorpius typus*) and soldier (*Cheimerius nufar*).

Almost half (44 per cent) of the yellowtail stomachs examined were empty. This might have been partly caused by their habit of periodic feeding. It has been observed that they sometimes remain in an area for days without taking bait or lures and then suddenly start to feed and to take bait and lures again.

Somewhat more than half (54 per cent) of the kob stomachs examined were empty because most were hooked near the sea-bottom and then hauled to the surface, causing them to regurgitate the stomach contents as a result of the inflation of the air bladders. The high percentage of empty elf (63 per cent) and silverfish (80 per cent) stomachs also reflected from

their habit of regurgitating the contents of their stomachs when caught (Van der Elst 1976, Nepgen 1977).

Fish were found to be the most important food item in the diet of predatory fish and ranged in occurrence from 46,3 per cent of the stomachs containing food, as in sharks, to 97,7 per cent as in snoek. Pelagic fish, particularly anchovy, were the

most common type of fish present in the diet. Other pelagic species found were pilchard, mackerel, horse mackerel and round herring.

The frequency of occurrence of the principal food items in the stomachs of predatory and reef fish caught in False Bay are listed in the following sections.

Predatory fish

SNOEK — *Thyrsites atun* (Euphrasen)

Number of stomachs	1 738	
Number empty	670	(39%)
Number containing food	1 068	(61%)
Range of fish fork length	65-99 cm	

Of the 1 068 snoek stomachs containing food, 1 043 (98%) held fish and 1 016 (95%) pelagic fish.

The taxa found in these stomachs and the number and percentage of stomachs with food in which they occurred are listed below.

Pisces		1 043	(98%)
Anchovy	<i>Engraulis capensis</i>	946	(89%)
Pilchard	<i>Sardinops ocellata</i>	120	(11%)
Horse mackerel	<i>Trachurus trachurus</i>	12	(1%)
Round herring	<i>Etrumeus teres</i>	11	(1%)
Mackerel	<i>Scomber japonicus</i>	8	(<1%)
Snoek (juvenile)	<i>Thyrsites atun</i>	4	
Sandeel	<i>Ammodytes capensis</i>	3	
Sandcord	<i>Gonorhynchus gonorhynchus</i>	2	
Steentjie	<i>Spondyllosoma emarginatum</i>	2	
Hottentot	<i>Pachymetopon blochii</i>	2	
Garfish	<i>Scomberesox saurus</i>	1	
Elf	<i>Pomatomus saltatrix</i>	1	
Gurnard	<i>Trigla capensis</i>	1	
Sole	<i>Austroglossus</i> sp.	1	
Fish remains only		12	(1%)
Crustacea		4	(<1%)
Brachyura			
Crab (megalopa larvae)		2	
Crab remains		1	
Stomatopoda			
Mantis shrimp	<i>Squilla armata</i>	1	
Mollusca		14	(1%)
Squid	<i>Loligo reynaudi</i>		

YELLOWTAIL — *Seriola lalandi* Valenciennes

Number of stomachs	906	
Number empty	398	(44%)
Number containing food	508	(56%)
Range of fish fork length	38-101 cm	

Of the 508 yellowtail stomachs that contained food, 348 (69%) had fish in them and 295 (58%) pelagic fish.

The taxa, numbers and percentages are listed below.

Pisces		348	(69%)
Anchovy	<i>Engraulis capensis</i>	237	(47%)
Pilchard	<i>Sardinops ocellata</i>	61	(12%)
Horse mackerel	<i>Trachurus trachurus</i>	13	(3%)
Mackerel	<i>Scomber japonicus</i>	3	(<1%)
Round herring	<i>Etruncus teres</i>	2	(<1%)
Garfish	<i>Scomberesox saurus</i>	5	(1%)
Sandeel	<i>Ammodytes capensis</i>	1	
Snoek (juvenile)	<i>Thyrsites atun</i>	1	
Mullet	<i>Liza richardsoni</i>	1	
Lantern-fish	<i>Myctophidae</i>	1	
Gurnard	<i>Trigla capensis</i>	1	
Fish remains only		32	(6%)
Crustacea		72	(14%)
Brachyura			
Crab (megalopa larvae)		70	(14%)
Macrura			
Rock lobster	<i>Jasus lalandii</i>	1	
Euphausiacea			
Euphausiid	<i>Nyctiphanes capensis</i>	1	
Euphausiid remains		1	
Mollusca		118	(23%)
Squid	<i>Loligo reynaudi</i>	117	(23%)
Octopus	<i>Octopus granulatus</i>	1	
Nautilus	<i>Argonauta argo</i>	1	
KOB — <i>Argyrosomus hololepidotus</i> (Lacépède)			
Number of stomachs		453	
Number empty		245	(54%)
Number containing food		208	(46%)
Range of fish total length		36-109 cm	

Of the 208 kob stomachs that contained food, 156 (75%) held fish and 84 (40%) pelagic fish.

The taxa and their numerical and percentage occurrence are listed below.

Pisces		156	(75%)
Anchovy	<i>Engraulis capensis</i>	70	(34%)
Horse mackerel	<i>Trachurus trachurus</i>	13	(6%)
Mackerel	<i>Scomber japonicus</i>	4	(2%)
Pilchard	<i>Sardinops ocellata</i>	2	(1%)
Sandeel	<i>Ammodytes capensis</i>	18	(9%)
Sandcord	<i>Gonorhynchus gonorhynchus</i>	14	(7%)
Hottentot	<i>Pachymetopon blochii</i>	2	(1%)
Silverfish	<i>Argyrozona argyrozona</i>	1	
Sand steenbras	<i>Lithognathus mormyrus</i>	1	
Piggy	<i>Pomadasys olivaceum</i>	1	
Klipfish	<i>Clinus</i> sp.	1	

Goby	Gobiidae	1	
Elf	<i>Pomatomus saltatrix</i>	1	
Sole	<i>Austroglossus</i> sp.	2	(1%)
Fish remains only		32	(15%)
Crustacea		42	(20%)
Stomatopoda		19	(9%)
Mantis shrimp	<i>Squilla armata</i>		
Euphausiacea		7	(3%)
Euphausiid	<i>Nyctiphanes capensis</i>		
Euphausiid remains			
Amphipoda		5	(2%)
Amphipod remains, semi-digested			
Brachyura		7	(3%)
Crab (megalopa larvae)		3	(2%)
Crab remains		4	(2%)
Macrura		1	
Rock lobster	<i>Jasus lalandii</i>		
Mollusca		24	(12%)
Squid	<i>Loligo reynaudi</i>	20	(10%)
Octopus	<i>Octopus granulatus</i>	3	(1%)
Cuttlefish	<i>Sepia officinalis</i>	1	

GEELBEK — *Atractoscion aequidens* (Cuvier)

Number of stomachs	124	
Number empty	42	(34%)
Number containing food	82	(66%)
Range of fish fork length	45-97 cm	

Of the 82 geelbek stomachs with food in them, 62 (76%) contained fish and 53 (65%) pelagic fish.

The taxa, numbers and percentages are listed below.

Pisces		62	(76%)
Anchovy	<i>Engraulis capensis</i>	36	(44%)
Horse mackerel	<i>Trachurus trachurus</i>	7	(9%)
Mackerel	<i>Scomber japonicus</i>	6	(7%)
Pilchard	<i>Sardinops ocellata</i>	3	(4%)
Round herring	<i>Etrumeus teres</i>	1	(1%)
Hottentot	<i>Pachymetopon blochii</i>	3	(4%)
Steentjie	<i>Spondyllosoma emarginatum</i>	1	(1%)
Snoek (juvenile)	<i>Thyrsites atun</i>	1	(1%)
Elf	<i>Pomatomus saltatrix</i>	1	(1%)
Silverside	<i>Hepsetia breviceps</i>	1	(1%)
Strepie	<i>Sarpa salpa</i>	1	(1%)
Lazy shark (juvenile)	<i>Poroderma africanus</i>	1	(1%)
Fish remains only		5	(6%)

Crustacea		2	(2%)
Stomatopoda			
Mantis shrimp	<i>Squilla armata</i>		
Mollusca		16	(20%)
Squid	<i>Loligo reynaudi</i>	14	(17%)
Octopus	<i>Octopus granulatus</i>	2	(2%)

ELF — *Pomatomus saltatrix* (Linnaeus)

Number of stomachs	226	
Number empty	143	(63%)
Number containing food	83	(37%)
Range of fish fork length	20-49 cm	

Of the 83 elf stomachs containing food, 60 (72%) had fish in them and 54 (65%) pelagic fish.

The taxa and their occurrence are listed below.

Pisces		60	(72%)
Anchovy	<i>Engraulis capensis</i>	47	(57%)
Horse mackerel	<i>Trachurus trachurus</i>	7	(8%)
Mullet (juvenile)	<i>Liza richardsoni</i>	2	(2%)
Fish remains only		3	(4%)
Crustacea		25	(30%)
Stomatopoda		17	(20%)
Mantis shrimp	<i>Squilla armata</i>		
Brachyura		6	(7%)
Crab (megalopa larvae)			
Euphausiacea		1	(1%)
Euphausiid remains			
Amphipoda		1	(1%)
Amphipod remains			
Mollusca		6	(7%)
Squid	<i>Loligo reynaudi</i>		

MACKEREL — *Scomber japonicus* Houttuyn

Number of stomachs	227	
Number empty	54	(24%)
Number containing food	173	(76%)
Range of fish fork length	28-49 cm	

Of the 173 mackerel stomachs with food, 100 (58%) held fish and 88 (51%) contained pelagic fish.

The taxa and their numerical and percentage occurrence are listed below.

Pisces		100 (58%)
Anchovy	<i>Engraulis capensis</i>	86 (50%)
Horse mackerel (juvenile)	<i>Trachurus trachurus</i>	2 (1%)
Windtoy	<i>Pterosmaris axillaris</i>	1 (<1%)
Fish remains only		11 (6%)
Crustacea		78 (45%)
Copepoda		67 (39%)
Various copepods, 80% of which were semi-digested	<i>Centropages brachiatus</i> <i>Calanoides carinatus</i> <i>Rhincalanus nasutus</i> <i>Nannocalanus minor</i> <i>Oithona similis</i>	
Brachyura		16 (9%)
Crab (megalopa larvae)		15 (9%)
Crab (zoea larvae)		1 (<1%)
Stomatopoda		8 (5%)
Mantis shrimp	<i>Squilla armata</i>	
Polychaeta		1 (<1%)
Bristle-worm		
SHARKS — <i>Carcharinus brachyurus</i> (Gunther), <i>Galeorhinus galeus</i> (Linnaeus) and <i>Mustelus nigropunctatus</i> Smith		
Number of stomachs		82
Number empty		28 (34%)
Number containing food		54 (66%)
Range of fish mass		2,1-24,0 kg

Of the 54 shark stomachs containing food, 25 (46%) had fish in them and 9 (17%) pelagic fish.

The taxa and their occurrence in stomachs with food are listed below.

Pisces		25 (46%)
Anchovy	<i>Engraulis capensis</i>	8 (15%)
Horse mackerel	<i>Trachurus trachurus</i>	1 (2%)
Shark (juvenile)	Various species	6 (11%)
Mullet	<i>Liza richardsoni</i>	3 (6%)
Silverfish	<i>Argyrozona argyrozona</i>	2 (4%)
Hottentot	<i>Pachymetopon blochii</i>	1 (2%)
Elf	<i>Pomatomus saltatrix</i>	1 (2%)
Sole	<i>Austroglossus</i> sp.	1 (2%)
Fish remains only		4 (7%)
Crustacea		19 (35%)
Brachyura		14 (26%)
Crab remains		
Macrura		5 (9%)
Rock lobster	<i>Jasus lalandii</i>	
Stomatopoda		1 (2%)
Mantis shrimp	<i>Squilla armata</i>	

Mollusca		21 (39%)
Cuttlefish	<i>Sepia officinalis</i>	8 (15%)
Octopus	<i>Octopus granulatus</i>	7 (13%)
Squid	<i>Loligo reynaudi</i>	6 (11%)
BAARDMAN — <i>Umbrina capensis</i> (Pappe)		
Number of stomachs		7
Number empty		2 (29%)
Number containing food		5 (71%)
No fish length determined		
Of the 5 baardman stomachs that contained food, 3 (60%) held fish and 2 (40%) pelagic fish.		
The taxa and their numerical and percentage occurrence are listed below.		
Pisces		3 (60%)
Anchovy	<i>Engraulis capensis</i>	2 (40%)
Mullet	<i>Liza richardsoni</i>	1 (20%)
Mollusca		1 (20%)
Octopus (juvenile)	<i>Octopus granulatus</i> ?	
Polychaeta		1 (20%)
Bristle worm		

SUMMARY

The high incidence of pelagic fish in the contents of snoek stomachs (i.e. in 95 per cent of the stomachs containing food) stresses the dependence of snoek on pelagic fish as food. Notwithstanding this, the activities of the purse-seine boats do not seem to have adversely affected the snoek catches in False Bay.

Anchovies were not as important in the diet of yellowtail as in that of snoek, but there was a similarity in the percentage occurrence of the other fish species in the stomach contents. Garfish appeared more often in the diet of yellowtail than of snoek, probably because yellowtail prefer warmer water where garfish are more likely to be present.

The percentage occurrence of pelagic fish in the diet of kob was the lowest of all the predatory bonefish, because kob tend to live mainly near the sea-bottom. For the same reason, non-pelagic fish, consisting of a variety of bottom and near-bottom living species, were much more common in kob stomach contents than in those of other predators.

Anchovy was the only fish species of any importance in the diet of elf. Except for the remains of juvenile horse mackerel in a few stomachs, juvenile mullet, found in the stomachs of elf caught close

inshore, were the only other fish present in their diet.

Sharks depended less than any of the other predators on pelagic fish for food, and anchovy, the most common pelagic fish in their diet, was present in only 15 per cent of the stomachs containing food. The three shark species sampled feed mainly on the larger crustaceans such as adult crabs and rock lobsters. Crabs especially, found in 26 per cent of the stomachs containing food, were important in their diet.

Crustaceans were important components in the diet of most of the predatory fish except snoek, geelbek and baardman. Megalopa crab larvae, which are sometimes present in shoals in the Cape Point area, and mantis shrimps were the most common crustaceans in the diet of the other predators.

Nearly 50 per cent of the diet of the sampled mackerel, which were all longer than 28 cm, consisted of crustaceans (mostly copepods and megalopa crab larvae), and just over 50 per cent of fish. Most stomachs contained either the one or the other type of food and in the few instances where both were present the stomachs did not contain much food. This is in accordance with a study done by Baird (1978), in which he found that small mackerel feed on zooplankton but as they grow larger crustaceans

decrease in importance as food while fish become more important. He also noted that either fish or zooplankton predominated and that few stomachs contained mixtures of these two groups.

Molluscs were common in the diet of predatory fish except snoek, elf and mackerel. Molluscs were completely absent in the stomach contents of

mackerel.

Although squid was the dominating mollusc in the diet of most predatory fish, cuttlefish and octopus were more often encountered in the stomach contents of sharks, probably because they were caught close inshore where these two mollusc species were more plentiful than squid.

Reef fish

RED ROMAN — *Chrysoblephus laticeps* (Cuvier)

Number of stomachs	101	
Number empty	21	(21%)
Number containing food	80	(79%)
Range of fish fork length	20-45 cm	

Of the 80 red roman stomachs with food, only one contained fish, namely klipfish.

The taxa and their numerical and percentage occurrence in stomachs containing food are listed below.

Pisces		1	(1%)
Klipfish	<i>Clinus</i> sp.		
Crustacea		23	(29%)
Brachyura		18	(23%)
Crab remains			
Macrura		4	(5%)
Rock lobster	<i>Jasus lalandii</i>		
Amphipoda		3	(4%)
Amphipod	<i>Parathemisto gaudichaudi</i> ?		
Isopoda		1	(1%)
Isopod remains			
Mollusca		15	(19%)
Black mussel	<i>Choromytilus meridionalis</i>	9	(11%)
Ribbed mussel	<i>Aulacomya ater</i>	1	(1%)
Fragmented shells only		5	(6%)
Chiton	<i>Dinoplax gigas</i>	1	(1%)
Octopus	<i>Octopus granulatus</i> ?	1	(1%)
Cuttlefish	<i>Sepia officinalis</i>	1	(1%)
Seaslug	<i>Doris verrucosa</i> ?	1	(1%)
Echinodermata		57	(71%)
Brittle star	Ophiuroidea	24	(30%)
Feather star	Crinoidea	13	(16%)
	e.g. <i>Comanthus wahlbergi</i>		
	<i>Dicrometra afra</i>		
	<i>Annametra occidentalis</i>		
Starfish	Asteroidea	12	(15%)
Sea urchin	Echinoidea	8	(10%)

Polychaeta	5	(6%)
Bristle-worm		
Sipunculida	2	(3%)
Peanut-worm		
Anthozoa	1	(1%)
Soft rock coral		
	<i>Eunicella papillosa</i> ?	

WHITE STUMPNOSE — *Rhabdosargus globiceps* (Cuvier)

Number of stomachs	78	
Number empty	16	(20%)
Number containing food	62	(80%)
Range of fish fork length	20-43	cm

Of the 62 white stumpnose stomachs with food, only two contained fish, and none of these were pelagic fish.

The taxa and their occurrence are listed below.

Pisces	2	(3%)
Elf	<i>Pomatomus saltatrix</i>	1 (2%)
Fish remains only		1 (2%)
Crustacea	12	(19%)
Amphipoda	9	(15%)
Amphipod remains		
Stomatopoda	4	(6%)
Mantis shrimp	<i>Squilla armata</i>	
Brachyura	2	(3%)
Crab remains		
Mollusca	32	(52%)
Octopus	<i>Octopus granulatus</i>	2 (3%)
Chiton	<i>Dinoplax gigas</i> ?	1 (2%)
Fragmented shells only	<i>Choromytilus meridionalis</i> & <i>Aulacomya ater</i> }	29 (47%)
Echinodermata	46	(74%)
Brittle star	Ophiuroidea	25 (40%)
Sea urchin	Echinoidea	10 (16%)
Feather star	Crinoidea	8 (13%)
	e.g. <i>Comanthus wahlbergi</i>	
Starfish	Asteroidea	3 (5%)
	e.g. <i>Asterina exigua</i>	
Polychaeta	6	(10%)

Bristle-worm		
Cirripedia		2 (3%)
Barnacle	<i>Balanus</i> spp.	
WHITE STEENBRAS — <i>Lithognathus lithognathus</i> (Cuvier)		
Number of stomachs		22
Number empty		6 (27%)
Number containing food		16 (73%)
Range of fish fork length		30-52 cm
None of the 16 white steenbras with food in their stomachs had eaten any fish.		
The taxa and their occurrence in stomachs with food are listed below.		
Crustacea		7 (44%)
Amphipoda		5 (31%)
Amphipod remains		
Brachyura		4 (25%)
Crab (megalopa larvae)		2 (13%)
Crab remains		2 (13%)
Isopoda		1 (6%)
Isopod remains		
Mollusca		14 (88%)
Chiton	<i>Polyplacophora</i> sp.	1 (6%)
Fragmented shells		14 (88%)
Echinodermata		2 (13%)
Sea urchin	Echinoidea	
Polychaeta		6 (38%)
Bristle-worm		

RED STUMPNOSE — <i>Chrysoblephus gibbiceps</i> (Cuvier)		
Number of stomachs		29
Number empty		4 (14%)
Number containing food		25 (86%)
Range of fish fork length		24-53 cm

None of the 25 red stumpnose that contained food had fish in their stomachs.

The taxa and their occurrence in stomachs with food are listed below.

Crustacea		10 (40%)
Brachyura		5 (20%)
Crab remains		
Macrura		3 (12%)
Rock lobster (puerulus stage)	<i>Jasus lalandii</i>	2 (8%)

Rock lobster	<i>Jasus lalandii</i>	1	(4%)
Stomatopoda		2	(8%)
Mantis shrimp	<i>Squilla armata</i>		
Mollusca		11	(44%)
Black mussel	<i>Choromytilus meridionalis</i>	4	(16%)
Octopus	<i>Octopus granulatus</i>	3	(12%)
Abalone (small)	<i>Haliotis midae</i>	2	(8%)
Fragmented shells		4	(16%)
Echinodermata		8	(32%)
Brittle star	Ophiuroidea	7	(28%)
Sea urchin	Echinoidea	1	(4%)
Polychaeta		4	(16%)
Bristle-worm			
Tunicata		3	(12%)
Red-bait	<i>Pyura</i> sp.		

SILVERFISH — *Argyrozona argyrozona* (Valenciennes)

Number of stomachs	50	
Number empty	40	(80%)
Number containing food	10	(20%)
Range of fish fork length	16-32 cm	

Of the 10 silverfish stomachs with food, 5 (50%) contained fish and 2 (20%) pelagic fish.

The taxa and their numerical and percentage occurrence in stomachs containing food are listed below.

Pisces		5	(50%)
Anchovy	<i>Engraulis capensis</i>	2	(20%)
Mullet (juvenile)	<i>Liza richardsoni</i>	1	(10%)
Fish remains only		2	(20%)
Crustacea		2	(20%)
Brachyura			
Crab (megalopa larvae)			
Mollusca		2	(20%)
Squid	<i>Loligo reynaudi</i> ?	1	(10%)
Octopus	<i>Octopus granulatus</i>	1	(10%)

HOTTENTOT — *Pachymetopon blochii* (Valenciennes)

Number of stomachs	99	
Number empty	17	(17%)
Number containing food	82	(83%)
Range of fish fork length	17-37 cm	

Of the 82 hottentot stomachs that contained food, only two (2%) had fish, namely klipfish, in them.

The taxa and their occurrence are listed below.

Pisces		2	(2%)
Klipfish	<i>Clinus</i> sp.	2	(2%)
Fish eggs		3	(4%)
Crustacea			
Amphipoda		33	(40%)
Various amphipods	<i>Caprella cicur</i> <i>Caprella equilibra</i> <i>Caprella mirabilis</i> <i>Paramoera capensis</i> <i>Parathemisto gaudichaudi</i>		
Brachyura		5	(6%)
Crab (zoea and megalopa larvae)			
Crab remains			
Copepoda		13	(16%)
Various copepods	<i>Calanoides carinatus</i> <i>Centropages brachiatus</i> <i>Metridia lucens</i> <i>Rhincalanus nasutus</i>		
Euphausiacea		2	(2%)
Euphausiid	<i>Nyctiphanes capensis</i>		
Isopoda		1	(1%)
Isopod remains	<i>Panathura</i> sp. ?		
Stomatopoda		1	(1%)
Mantis shrimp	<i>Squilla armata</i>		
Mollusca		7	(9%)
Abalone (small)	<i>Haliotis midae</i>		
Black mussel remains	<i>Choromytilus meridionalis</i> ?		
Bivalve larvae			
Echinodermata		26	(32%)
Brittle star	Ophiuroidea		
Feather star	Crinoidea		
	e.g. <i>Comanthus wahlbergi</i>		
Polychaeta		3	(4%)
Bristle-worm			
Hydrozoa		9	(11%)
Various hydrozoans	<i>Antennella</i> sp. <i>Plumularia setacea</i> ? <i>Salacia articulata</i> <i>Symplectocyphus</i> sp.		

Anthozoa		1 (1%)
Sea-anemone	Actiniaria	
Bryozoa		2 (2%)
Various bryozoans	<i>Bicellaria ciliata</i> <i>Menipea crista</i>	
Tunicata		1 (1%)
Red-bait	<i>Pyura</i> sp.	
Sipunculida		1 (1%)
Peanut-worm		
Scyphozoa		2 (2%)
Fragmented jelly-fish		
Seaweeds		26 (32%)
Various algae	<i>Carpoblepharus flaccida</i> <i>Caulerpa holmesiana</i> <i>Junia</i> sp. <i>Plocamium suhrii</i>	
Red seaweeds	Rhodophyta	

OTHER REEF FISH

A few stomachs of other reef fish were examined in order to obtain an indication of their diet in False Bay.

- (i) Red steenbras — *Petrus rupestris* (Valenciennes) — Pelagic fish were not found in the four stomachs examined, but steentjie (*Spondylionema emarginatum*) and klipfish (*Clinus* sp.) remains were found singly in two of the stomachs.

Other items in the stomachs were crustaceans such as mantis shrimps and amphipods. The only mollusc found was the remains of giant periwinkle (*Turbo sarmaticus*) in one stomach and the only echinoderm, the fragmented remains of a brittle star in another stomach.

- (ii) Galjoen — *Coracinus capensis* (Cuvier) — As can be expected, because they do not even take fish bait, no fish were found in the four galjoen stomachs examined.

Fragmented black mussel shells were found in all the stomachs containing food. Crustaceans found were megalopa stages of crab

larvae and a few amphipods. Annelida were found in one stomach only, which was well-filled with bristle-worm (Polychaeta) remains. Remains of sponges (Porifera) were present in one stomach.

- (iii) Musselcracker — *Cymatoceps nasutus* (Castelnau) — Three musselcracker stomachs were examined and all contained fragmented mollusc shells. No fish or other food items were identified in the stomachs.
- (iv) Panga — *Pterogymnus laniarius* (Cuvier) — Except for a section from the jaw of a small fish, no other traces of fish were found in any of the three stomachs examined.

Mollusc remains were present in all the stomachs examined and consisted mainly of fragmented shells and a few larval bivalves.

Remains of semi-digested amphipods were present in two of the stomachs while a small number of copepods, amongst which *Calanoides carinatus* and *Rhincalanus nasutus* could be identified, was present in one stomach.

Fragmented brittle stars were seen in one stomach and bristle-worm remains in two.

- (v) Blue hottentot — *Pachymetopon aeneum* (Gilchrist & Thompson) — Fish were not found in the three stomachs examined, and the only food items encountered in the stomachs were squid remains in one stomach and bristle-worm remains in another.

SUMMARY

It is evident from the results that fish were unimportant in the diet of the reef fish examined and that their food consisted mainly of food items found on or near the sea-bed. The catches of purse-seiners in False Bay should therefore have no effect on their food supply.

Crustaceans such as megalopa crab larvae and adult crabs and amphipods were common in the diet of reef fish. The *Caprella* spp. recorded in the stomachs of hottentot were encountered only in stomachs containing algae and were therefore probably eaten along with it.

Unidentifiable fragmented mollusc shells were present in the stomach contents of most reef fish, especially the white steenbras. Although some of these fragmented shells might have been the remains of molluscs that were actually eaten, the bulk probably resulted from their way of searching for food. The feeding habits of the white steenbras include the sucking in and blowing out of sand with their protrusible lips (Mehl 1973). During this process fragmented shells, present everywhere on the sea-floor of False Bay (Bowie *et al.* 1970), are readily swallowed.

The molluscs in the diet of the reef fish were all bottom-living species except for squid remains found in one silverfish stomach.

Echinoderms constituted an important component of the diet of reef fish. The most common echinoderms were brittle stars, feather stars and sea urchins.

Hottentot, known to be omnivorous, was the only species with algae in its diet.

THE LINE FISHERY AND EFFECTS OF SEINING

There are no restrictions on the line fishermen as to when and where they may fish, except for a small reserve established in 1979 on the western side of the Bay where no fishing is allowed. The activities of the purse-seine boats are more curtailed. Those fishing for the processing factories, of which none

Table I: Number of boats with commercial licenses registered in the False Bay area, 1968-1979

Year	Number of boats
1968	443
1969	549
1970	607
1971	593
1972	594
1973	645
1974	637
1975	657
1976	650
1977	698
1978	699
1979	712

are situated in False Bay, are allowed to fish in there for three-and-a-half months (15 January — 30 April) each year, but those fishing for bait are permitted to fish the year round.

The number of beach seine-nets has been controlled by regulation since 1974, but not the numbers of anglers, handline and spear fishermen. As the population grew and enjoyed more leisure time, the recreational fishermen in the Bay increased. The number of licensed boats in False Bay, for example, increased by 61 per cent between 1968 and 1979, from 443 to 712 (Table I). This naturally resulted in an increased fishing effort, directed mainly towards line-fish.

The catch and fishing effort of commercial purse-seiners are much better documented than those of line-fishermen, whether recreational or commercial.

Line fishery

Line-fishing is conducted by professional and recreational or game fishermen who use lines and hooks and a variety of lures and bait such as squid, pilchard, red bait, mussel and worm. All the professional fishermen and some of the game fishermen fish from boats with hand lines. Some of the fish caught are off-loaded at the two proclaimed fishing harbours, Gordon's Bay and Kalk Bay, but a substantial amount is landed on sandy beaches or in small bays where there are no harbour facilities. Most amateurs off-load outside the official harbours. The rock and surf anglers are all amateurs and fish with rods and lines, usually for bony fish.

An examination of the records of these anglers for the period 1970—1979 revealed that all of the species mentioned earlier, in the feeding section, appeared in their catches as well as a few strepie and bonito (*Sarda sarda*).

Table II: Shark catches made during Western Province rock and surf angling competitions in False Bay

Year	Number of sharks caught	Effort (man-days)	Number of sharks caught per man-day	Average weight of sharks caught (kg)
1971	195	1 361	0,14	15,0
1972	191	1 165	0,16	14,9
1973	307	1 284	0,24	18,4
1974	202	1 183	0,17	14,5
1975	174	1 412	0,12	15,9
1976	232	1 150	0,20	14,3
1977	324	1 521	0,21	13,9
1978	358	1 690	0,21	13,8
1979	584	1 591	0,37	13,8

The only reliable statistics of line catches in False Bay over a number of years are those for sharks caught during competitions of the Western Province Rock and Surf Angling Union, and those for snoek. Because fishing during the competitions is directed towards the catching of sharks, because they weigh more, the catch of bony fish could almost be looked upon as a by-catch, and it cannot therefore be used to determine fluctuations in the availability of teleosts. The annual results of competitions, in which sharks were caught, are listed in Table II for the years 1971 — 1979.

It is clear that there was a steady increase in the total number of anglers participating annually in the competitions, an increase in the number of sharks caught, a steady decrease in the average weight (mass) of the sharks caught although this has remained almost constant for the last three years, and an increase in the catch per unit effort.

The gradual decline in the average weight of sharks possibly indicates that the shark population was affected by exploitation. This does not necessarily mean that there has been overfishing, because the annual mean weight during the last three years (1977 — 1979) remained virtually the same while the number of sharks caught per unit of effort (man-day) increased. It seems, therefore, that the catching of pelagic fish in the Bay did not affect the population size of sharks.

As stated above, the statistics of snoek catches made in False Bay are fairly reliable and cover a long period. It is therefore interesting to note that, although purse-seine boats catch a portion of the pelagic fish shoals on which the snoek preys and scatter some shoals during their fishing operations, their activities do not seem to have adversely affected the snoek catches in False Bay. For example, during the years 1921 — 1931, before the establishment of the pelagic shoal fishery, 14,5 per

Table III: False Bay and total South African snoek catches, 1921 - 1931 and 1971 - 1980

Year	False Bay catch (numbers)	Total South African catch (numbers)	False Bay catch as percentage of total catch
1921	306 222	2 469 536	12,4
1922	30 364	1 445 905	2,1
1923	97 769	1 321 201	7,4
1924	119 661	1 118 325	10,7
1925	393 889	1 563 051	25,1
1926	42 905	1 129 072	3,8
1927	440 283	3 261 356	13,5
1928	342 937	2 271 104	15,1
1929	490 866	1 583 439	31,0
1930	154 752	1 218 520	12,7
1931	210 345	767 683	27,4
1921-1931	2 629 993	18 149 192	14,5
1971	73 380	1 334 396	5,4
1972	32 187	905 349	3,6
1973	152 057	1 777 006	8,6
1974	479 198	2 249 253	21,3
1975	852 038	2 219 083	38,4
1976	1 099 943	4 670 268	23,6
1977	585 889	2 303 140	25,4
1978	230 167	2 393 928	9,6
1979	437 107	1 368 177	31,9
1980	205 649	678 956	30,3
1971-1980	4 147 615	19 899 556	20,8

cent of the total South African snoek catch was made in False Bay. From 1971 to 1980, when purse-seining occurred in the Bay or parts of it, 20,8 per cent of the total snoek catch was landed there (Table III). (If taken over the period 1974—1980, the average percentage of snoek caught in False Bay was even higher, 24,4 per cent of total catches.)

Purse-seine fishery

The boats fishing for pelagic fish for the factories use large purse-seine nets which are 200—250 fathoms long and 30-35 fathoms deep. These nets are expensive and are therefore not used where rocky outcrops on the sea-bottom may tear them. The pelagic bait boats are limited to a net not greater than 50 fathoms long and 8 fathoms deep.

Six species, i.e. anchovy, pilchard, round herring, horse mackerel, mackerel and lantern-fish, contribute to the South African pelagic purse-seine fishery. Of these, lantern-fish have never been caught in False Bay because the water is too shallow for bathypelagic species. Also, only small quantities of horse mackerel and mackerel have been caught

Table IV: False Bay and total South African pelagic fish catches

Year	False Bay catch (metric tons)	Total South African catch (metric tons)	False Bay catch as percentage of total catch
1964	28 345	425 657	6,7
1965	11 204	480 160	2,3
1966	2 425	357 163	0,7
1967	1 405	508 448	0,3
1968	10 143	368 820	2,8
1969	4 383	351 979	1,2
1970	3 023	358 912	0,8
1971	11 245	325 680	3,5
1972	4 372	433 624	1,0
1973	4 071	451 415	0,9
1974	20 008	400 513	5,0
1975	26 766	407 438	6,6
1976	21 406	407 562	5,3
1977	5 682	357 220	1,6
1978	36 874	380 362	9,7
1979	15 781	380 940	4,1
1980	25 804	380 804	6,8
1964-1980	232 937	6 776 697	3,4

Table V: Pelagic fish catches made in False Bay by boats operating out of Gans Bay and Hout Bay

Year	Total catch (metric tons)	False Bay catch (metric tons)	Percentage of total catch caught in False Bay
<i>Gans Bay</i>			
1977	28 780	0	0
1978	28 859	39	0,1
1979	28 805	240	0,8
1980	28 950	0	0
1977-1980	115 394	279	0,2
<i>Hout Bay</i>			
1977	40 446	147	0,4
1978	40 201	8 299	20,6
1979	40 310	14 567	36,1
1980	40 225	6 216	15,4
1977-1980	161 182	29 229	18,1

there. Anchovy is the most plentiful pelagic species in the Bay. During the period 1977—1980, the total catch of 84 142 tons made in False Bay contained 52 943 tons (63 per cent) anchovy and 24 806 tons (29 per cent) pilchard.

Even so, the pelagic fish caught by purse-seiners in False Bay since 1964 constituted an average of only 3,4 per cent of the total South African annual pelagic fish catch (Table IV). The general trend is, however, that the portion of the annual catch made in False Bay is slowly increasing. For the years 1964—1971, only 2,3 per cent of the total catch came from False Bay compared with 4,5 per cent for the years 1972—1980. The average annual catch of pelagic fish in False Bay between 1964 and 1971 (9 022 tons) increased by 98 per cent to 17 862 tons for the period 1972—1980.

The amount of pelagic fish caught in False Bay does not only depend on abundance, but also to a large extent on availability in areas closer to the fish processing factories. When there are shoals of pelagic fish nearer to the factories, the purse-seiners will rather fish closer to their home bases than steam the longer distance to False Bay. In 1979, for example, when pelagic fish were available in the proximity of most of the West Coast factories, their purse-seiners caught only 974 tons in the Bay. The boats from Gans Bay caught only 240 tons in False Bay, while the boats from Hout Bay, in the immediate vicinity, caught 14 567 tons.

The importance of False Bay as a fishing area for the two nearest factories (Gans Bay and Hout Bay) is shown in Table V for the years 1977—1980. It is evident that the contribution of False Bay to the total Gans Bay pelagic fish catch, where both a cannery and a fishmeal plant are located, is small. In contrast, False Bay is of great importance as a fishing area for the boats from Hout Bay, where only a fishmeal plant is located. More than 24 per cent of the pelagic catch processed at Hout Bay came from False Bay in the period 1978—1980. The pelagic fish quota has remained virtually static in recent years.

Because the bait boats fish mainly for pilchard, which are less plentiful than anchovy in False Bay, their total catch in the Bay is small. In 1979, for instance, they caught only 59 tons in False Bay, which is 2,8 per cent of the total bait-boat catch for that year.

The False Bay catches of purse-seiners stationed at Hout Bay from March to April 1979, when the factory filled its catch quota, contained only a few gurnards as by-catch.

During 1980, purse-seiners from Gans Bay did not fish in False Bay, but boats from Hout Bay, Saldanha Bay and St Helena Bay did, catching a total of 25 804 tons of pelagic fish in 381 throws. Hout Bay boats caught 6 216 tons or 15,4 per cent of their total 1980 pelagic catch in False Bay (Table V).

Examination of catches made in the Bay and landed at Hout Bay during 1980 showed that the total by-catches made in False Bay consisted of 70—80 snoek and a few gurnards. One St Helena Bay

boat had between 15 and 25 kob mixed with its catch.

The indications are therefore that the by-catches made by the purse-seiners fishing for pelagic fish in False Bay are negligible.

DISCUSSION

Catches by purse-seiners in False Bay indicated that anchovy, and to a lesser extent pilchard, was the most plentiful pelagic shoal fish in the Bay. It is also clear that pelagic fish, especially anchovy, are important as food for the predatory fish in False Bay, but not for the reef fish.

The fishing activities of pelagic purse-seiners in the Bay are limited. The majority of the fish factories and bait boats obtain only a small percentage of their catch in False Bay, though the factory at Hout Bay relies to a somewhat larger extent on False Bay catches to fill its catch quota.

It is also manifest that by-catches made by purse-seine vessels in the form of reef or predatory species are negligible and can have no effect on the availability of these species, though feared so by the angling fraternity.

Purse-seiners were accused of breaking up the shoals of pelagic fish by their activities, thus making it more difficult for predatory species to obtain food. This may be partly true, but if it should have an effect on the availability of these species in the Bay, it is difficult to understand why a higher proportion of the total South African catch of snoek, the most important predator on pelagic fish in the Bay, came from False Bay or why about 60 per cent of elf and yellowtail stomachs containing food still contained pelagic fish.

Many recreational fishermen are of the opinion that their individual catches are so small that they should not have any effect on the resource. Unfortunately, there is no information regarding their total catch, but its magnitude may surprise even them if the statistics could be gathered. If the problems of the line-fishermen are to be properly assessed, co-

operation in providing the necessary data would be urgently required.

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SUGGESTED EXPLANATION FOR A SHIFT IN CATCH POSITIONS OF JUVENILE ANCHOVY OFF SOUTH WEST AFRICA IN 1978

R.M. THOMAS, J.D. HEWITSON and H. BÖHME

Daily anchovy catch positions have been plotted for the 1978 fishing season off South West Africa. Evidence is given that a large-scale northward movement of juveniles was caused by shortage of food.

Daaglikse ansjovis-vangposisies is vir die 1978-vangseisoen langs die kus van Suidwes-Afrika gekarteer. Daar word bewys gelewer dat 'n beweging op groot skaal noordwaarts van jongvis deur voedseltekort veroorsaak is.

Each year, usually in May, large shoals of juvenile anchovy appear in the vicinity of Walvis Bay. They are geographically separate from the adult anchovy shoals, which are found close inshore north of 20° 50'S (Sea Fisheries Institute, unpublished data). Purse-seiners of the Walvis Bay fishing fleet make large catches of these juvenile anchovy when they appear. In 1978, the daily catch positions of the juvenile anchovy were examined for trends in, and reasons for, migrations of the shoals.

After each fishing trip skippers are required to complete a form giving, among other details, the position of each catch and the estimated tonnage. The position of each catch is given as the number of hours steaming time from Walvis Bay, the direction and the depth. Anchovy catch positions were noted for every catch over 10 tons, and mean daily catch positions were calculated.

Figure 1 shows catch positions for part of the 1978 fishing season. The shaded area represents the range of catch positions from 26 April until 27 May. The dots are the mean daily catch positions from 26 April until 6 June. From the time of the appearance of juvenile anchovy on 26 April until 27 May, the catch area was small and shoals appeared to be wheeling around slowly despite heavy fishing pressure (for clarity most of the mean daily catch positions on Figure 1 have been left undated). Later, as reflected on Figure 1, the area in which the shoals moved increased and an apparent migration took place to the north of Cape Cross. This was followed by a return to the Walvis Bay area. The length frequency distributions of the landings showed that the same group of fish was being exploited by the purse-seiners throughout (Sea Fisheries Institute, unpublished data).

There is evidence that the movement was a migration in search of food. Figure 2 shows the mass of food in the stomach and the frequency of empty

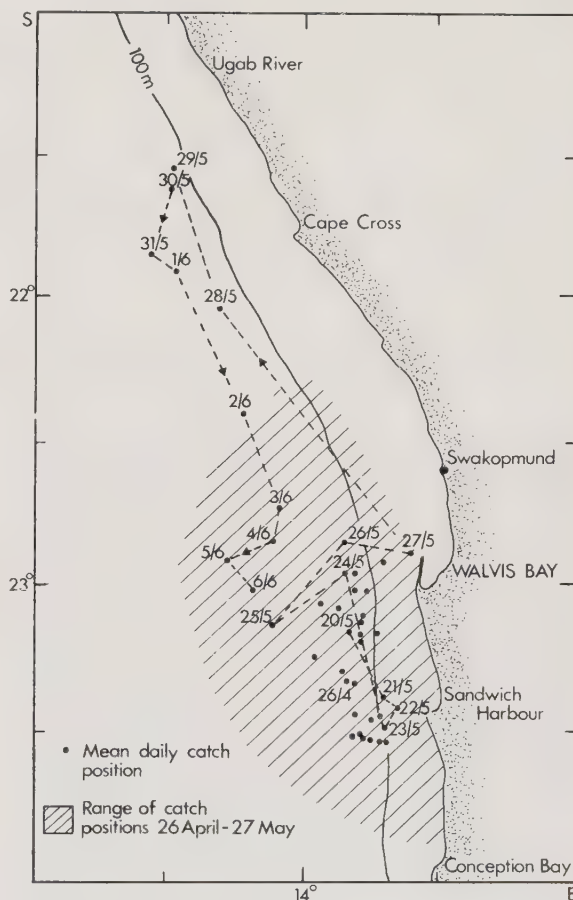


Fig. 1: Catch positions of juvenile anchovy for part of the 1978 fishing season (bathymetry from Bremner 1981)

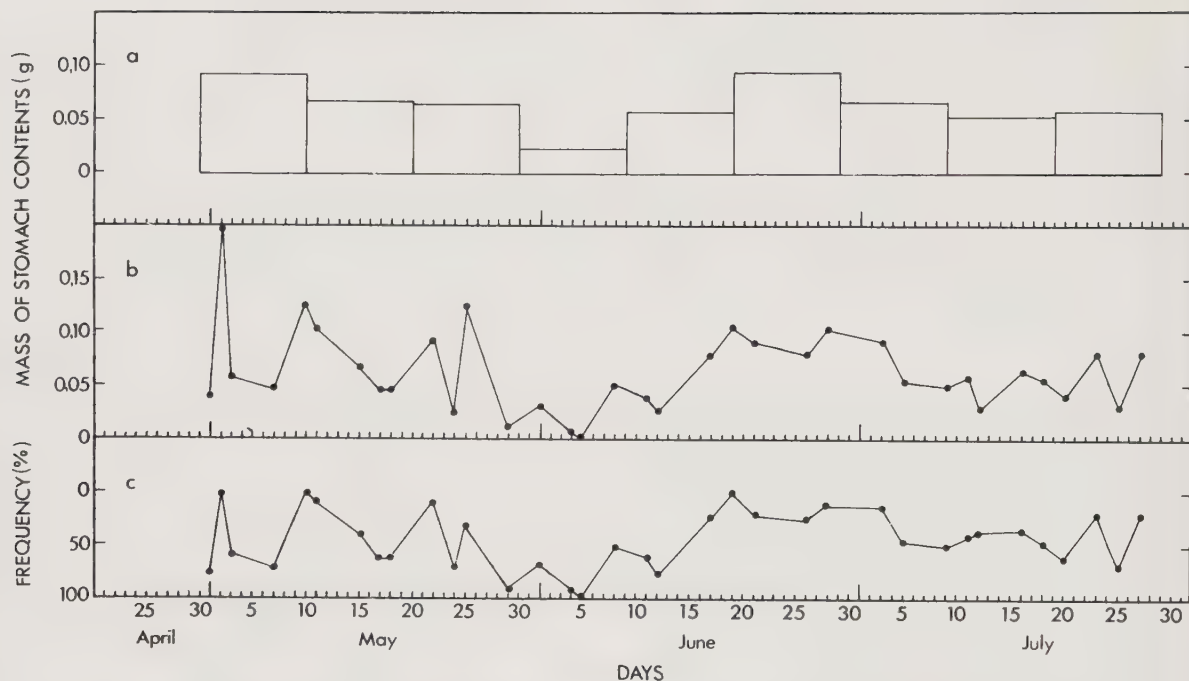


Fig. 2: Stomach repletion and content mass of juvenile anchovy in 1978: (a) mean mass of stomach contents at 10-day intervals; (b) mean mass of stomach contents; (c) frequency of empty stomachs

stomachs during the 1978 season. There was a clear minimum in the mass of food in the stomach between 29 May and 5 June.

When boats search for fish they normally fill up on the first large shoals encountered on their outward journey. If catches were made only at the edge of an area of high abundance the catch positions would shift the apparent position of the total area of abundance towards Walvis Bay. This shift would be unlikely to be pronounced because the large numbers of boats searching would soon locate the areas of highest abundance, unless the fish had moved rapidly away from the location of the previous days' catches. Also, the anchovy could sometimes appear in more than one area per day, and when this happened both areas appeared in the plotted catch positions.

Mean daily catch positions presented here indicate that the anchovy shoals migrated continuously around the area where they had first been discovered. The large movement north could have been the result of an absence of food, notably phytoplankton. Phytoplankton and the zooplankton which grazes on it collectively constitute the main dietary preference of juvenile anchovy (King and Macleod 1976).

In conclusion, the following reconstruction of

events is put forward.

In early May, catches were located in a small area and the daily movement of the fish shoals appeared small. Heavy exploitation did not "frighten" the fish away, as is sometimes claimed. However, as food became more scarce the movement increased. On 28 May the mean catch position shifted north. Only eight catches were made that day, either because the shoals had broken up or more likely because they had moved so far away that the boats had difficulty in finding them. On 30 May the number of catches reverted to about thirty per day. The mean mass of food in the stomach was low at this time, which suggests that the shoals were searching for food. The overall speed during this migration, calculated from the daily shift of catch positions, was not less than 20 nautical miles per day.

Often, the movement of shoals is reported by fishermen to be new waves of fish. However, the impression gained from this analysis of the 1978 catch positions is that much of the so-called new fish is actually the same shoal group wheeling around searching for food. If it moved away suddenly and then returned it would give the impression of an incoming wave.

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ENVIRONMENTAL ASPECTS OF A FEW PELAGIC FISH SHOALS OFF SOUTH WEST AFRICA

I. KRUGER AND R.A. CRUICKSHANK

Limited ecological studies of fish shoals were carried out off South West Africa during June 1973 and April 1974. The feeding habits of the fish are discussed in terms of the available food organisms, stomach content weights relative to maturity stage and the location of the fish in relation to phytoplankton concentrations in the environment. The degree to which the abiotic environment (wind, temperature, salinity and oxygen concentration) affects the behaviour of the fish shoals is also discussed.

Gedurende Junie 1973 en April 1974 is beperkte ekologiese studies oor visskole langs die kus van Suidwes-Afrika uitgevoer. Die voedingsgewoontes van die vis word bespreek na aanleiding van die beskikbare voedselorganismes, pensinhoudgewigte relatief tot rypheidstadia en die ligging van die vis ten opsigte van die fitoplanktonkonsentrasie in die omgewing. Die mate waarin die abiotiese omgewingstoestande (wind, temperatuur, soutgehalte en suurstofkonsentrasie) die gedrag van die visskole beïnvloed, word ook bespreek.

A study of the biology and population dynamics of pelagic fish species in relation to their immediate biotic and abiotic environment is useful, in that such information on fish shoal ecology can be used to assist in rational management of the fisheries. Andrews (1974) also stressed the need to understand the relationship between each fish species and its environment in order to ensure proper fisheries management.

Investigations of fish shoal ecology were conducted during the Cape Cross Programme, a multi-disciplinary research programme in the area between 17°S and 24°40'S. It was carried out during the period 1970-1974, with the major aim of investigating the decline of the pilchard *Sardinops ocellata* stock following peak landings in 1968. The present report deals with pilchard and anchovy *Engraulis capensis* shoals, their feeding and aspects of their immediate environment, all of which were studied during June 1973 and April 1974. The observations are discussed in the light of the findings of other workers in this field.

BACKGROUND

A synopsis of the feeding of the South West African pilchard was given by Matthews (1960) with short notes on the environmental conditions. More detailed feeding studies on pilchard and anchovy were conducted by Macleod (1972), King (1973) and King and Macleod (1976). Davies (1957) made a fairly detailed study of the feeding of the South African pilchard off the west coast of South Africa, and a synopsis of its feeding and ecology was given by De Jager (1959). Stander (1964), Du Plessis (1967)

and O'Toole (1980) have detailed the patterns of the hydrological regime of South West African waters. Kruger (1972), De Vos and Visser (1972), Visser *et al.* (1973) and Wessels *et al.* (1974) discussed the relationship between pelagic fish and their environment off South West Africa. Agenbag (1980) reported on the distribution of pelagic fish as influenced by hydrology. He earlier investigated vertical migration of pelagic fish shoals and the influence of the moon on them (Agenbag 1973). This report covers the results of two brief sampling cruises in 1973 and 1974. Limited biological data are looked at in relation to hydrological parameters and to phytoplankton availability for three anchovy and eight pilchard shoals.

MATERIAL AND METHODS

Shoal detection and sampling

Scientific observations were made of eight shoals in June 1973 (winter) and three shoals in April 1974 (autumn). In a co-operative effort between six commercial boats and two research vessels of the Sea Fisheries Institute, sample catches were made of the eight shoals in June. Shoals 9-11 were studied in April 1974 from two of the Institute's research vessels and a chartered aircraft. Hydrological and acoustic data were recorded and samples of the fish and the plankton were collected. Subsamples of 25 fish were taken from each of the catches made during the June survey after bulk sample analysis (for length frequencies) had been completed. No fish samples were collected from Shoals 9-11 because no catcher vessel was employed.

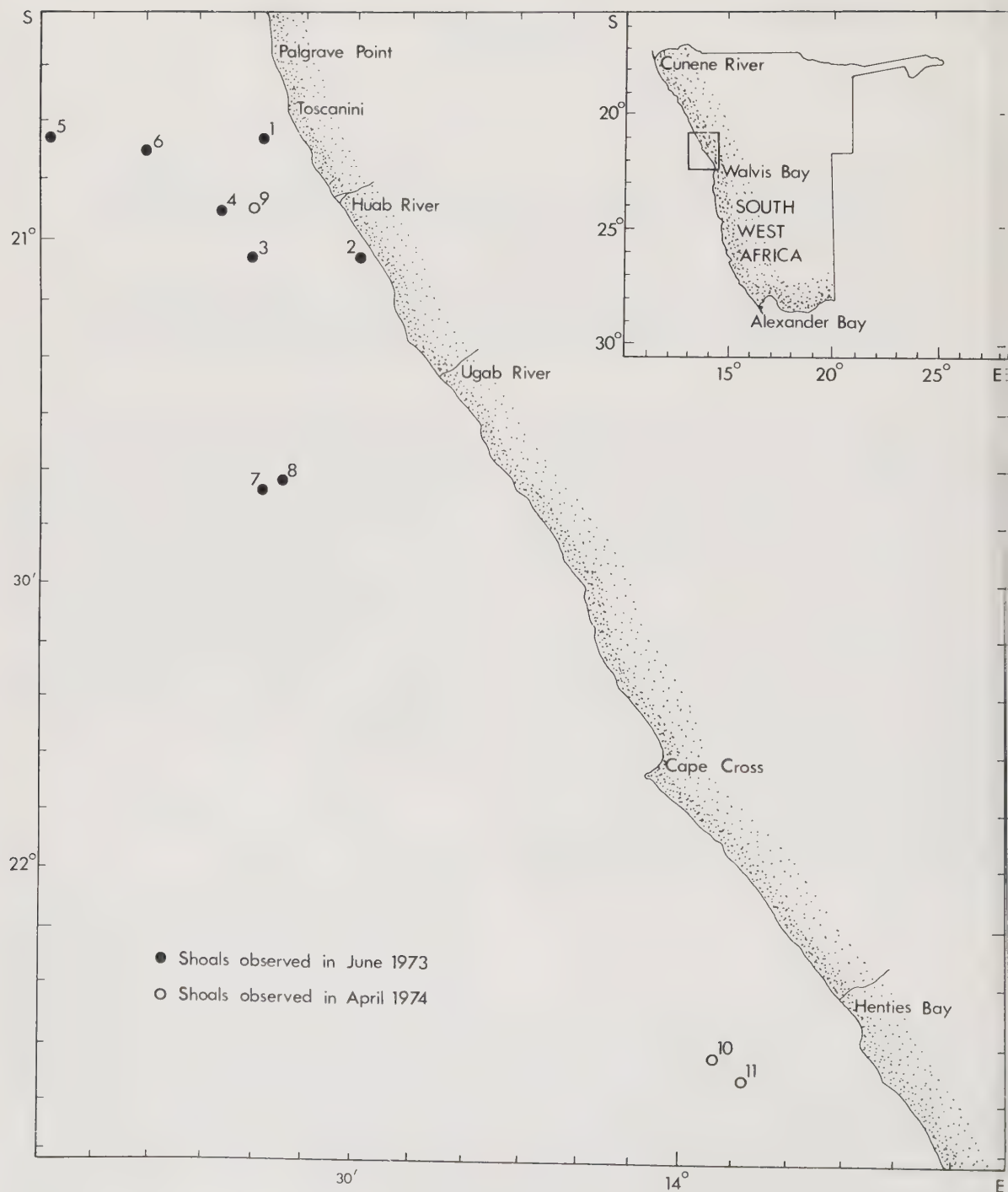


Fig. 1: Positions of shoals

Environmental sampling

A Nansen-Pettersson bottle was used to collect samples for salinity and oxygen determination and to record the temperature at various depths.

In June 1973, the bottle samples also served for quantitative phytoplankton analysis. In April 1974, at Shoals 9–11, the phytoplankton was only qualitatively sampled by means of closing-net hauls.

Wind data were recorded from a ship-borne anemometer.

Biological analysis

Quantitative and qualitative phytoplankton samples were analysed according to the methods used by Nel (1968). Phytoplankters were identified to species level (Appendix), counted and the percentage composition of the most important groups calculated. The small quantities of zooplankton collected were not analysed.

Average fresh weight (mass) of stomach contents, frequency of maturity stage per subsample and overall mean weight of stomach contents per maturity stage were determined for anchovy and pilchard. The maturity stages are as described by Davies (1956).

SHOAL PARAMETERS

Shoal positions

Shoal positions are plotted on Figure 1. Shoals 1, 6 and 5 were respectively 7, 29 and 44 km off Toscanini. Shoals 9 and 4 were 16 and 22 km off the

Huab River, whereas Shoals 2 and 3 were south of the river, 4 and 22 km off shore. South of the Ugab River, shoals 7, 8, 10 and 11 were respectively 44, 40, 27 and 24 km off shore.

Shoal identification

The species composition of Shoals 1–8 was determined from purse-seine catches. Shoals 9–11 were located by chartered aircraft, and Shoals 10 and 11 were identified by their characteristic shoal form. Shoal 9 was not identified because of poor visibility. The identities of the shoals are listed in Table I.

Shoal depth and thickness

The maximum depth of all shoals caught in June 1973 (except Shoal 2) was 30–40 m below the surface, but in April 1974, no part of any shoal was deeper than 12 m (Table I). The upper limits of the June shoals were 2–27 m deep, and those of the April shoals 0–4 m. Vertical thickness of winter shoals was greater than 18 m in five instances and 5 m or less in three. Autumn shoals were all between 5 and 11 m thick.

Maturity and feeding

Subsamples totalling 200 fish were measured for length, and the sex, stomach weight and maturity stages were determined. All fish were adult. Anchovy lengths (L_c) ranged from 102 to 154 mm (75 fish) and pilchard from 194 to 256 mm (125 fish).

Average stomach weights per subsample of the three anchovy and five pilchard shoals are given in

Table I: Fish shoals sampled in June 1973 and April 1974

Shoal number	Species	Date sampled	Time caught	Mass caught (metric tons)	Sounding (m)	Shoal depth (m)
1	Anchovy	14.6.73	09h10	1.0	35	27-30
2	Anchovy	15.6.73	06h10	0.1	15	6-10
3	Anchovy	15.6.73	19h04	3.6	96	2-30
4	Pilchard	15.6.73	20h00	44.8	100	8-36
5	Pilchard	16.6.73	14h30	49.9	120	25-30
6	Pilchard	16.6.73	15h00	51.1	113	18-36
7	Pilchard	17.6.73	12h05	36.7	115	13-40
8	Pilchard	17.6.73	13h33	88.2	113	11-36
9	Not identified	22.4.74	05h00*	None	76	0-11
10	Pilchard	23.4.74	22h15*	None	71	0-5
11	Pilchard	23.4.74	23h30*	None	66	4-12

* Time observed on echo sounder

Table II: Stomach weight and maturity of fish in each shoal

Date	Shoal number	Species	Time caught	Average stomach weight (g) per subsample of 25 fish	Maturity (percentage of each subsample of 25 fish)						
					Inactive	Active	Spent/spent-inactive				
14.6.73	1	Anchovy	09h10	0,084	72	8	20				
15.6.73	2	Anchovy	06h10	0,056	64	4	32				
15.6.73	3	Anchovy	19h04	0,248	16	4	80				
15.6.73	4	Pilchard	20h00	0,264	12	76	12				
16.6.73	5	Pilchard	14h30	0,192	8	48	44				
17.6.73	6	Pilchard	15h00	0,140	12	48	44				
17.6.73	7	Pilchard	12h05	0 176	20	72	8				
17.6.73	8	Pilchard	13h33	0,228	8	79	13				
Total for all subsampled fish											
Inactive				Active				Spent/spent-inactive			
Number of fish		Average stomach weight (g)		Number of fish		Average stomach weight (g)		Number of fish		Average stomach weight (g)	
Anchovy	Pilchard	Anchovy	Pilchard	Anchovy	Pilchard	Anchovy	Pilchard	Anchovy	Pilchard	Anchovy	Pilchard
38	15	0,068	0,133	4	80	0,100	0,209	33	30	0,200	0,210

Table II. In addition, the overall mean stomach weights for the sexual stages inactive, active and spent/spent-inactive were calculated from the 75 anchovy and 125 pilchard. These stomach weights were tested statistically against time caught and the three maturity groups mentioned above for both species. The data are too few for valid statistical analysis, but statistical tests (Anovar or *t*-test) were applied to check the strength of the trends suggested.

The mean stomach weight of the anchovy caught in the evening was significantly higher at the 5-per-cent level (Anovar test: $F_3 = 36,1$; $df = 2$ and 72) than those caught in the morning. Overall mean stomach weight of the maturity group spent/spent-inactive for anchovy caught in the evening was significantly higher at the 5-per-cent level (Anovar test: $F_3 = 14,09$; $df = 2$ and 72) than that of inactive and active fish. Eighty per cent of the anchovy Shoal 3, caught at 19h00, were spent/spent-inactive, whereas Shoals 1 and 2 caught in the morning and at dawn respectively, consisted of nearly 70 per cent fish in the inactive stage. In all three shoals, only about 5 per cent were active.

The stomach weights of pilchard caught from midday to evening did not significantly differ (Anovar test: $F_3 = 1,58$; $df = 4$ and 120). Also, no significant difference in stomach weights of the three maturity groups was found (Anovar test: $F_3 = 1,03$; $df = 2$ and 122). Almost 76 per cent of the fish in Shoals 4, 7 and 8 were in the active condition, 13 per cent were inactive and 11 per cent spent/spent-inactive. Shoals 5 and 6 contained 46 per cent active

fish, 44 per cent spent/spent-inactive and 10 per cent inactive (Table II). Shoals 5 and 6 were caught in mid-afternoon, Shoals 7 and 8 at midday and Shoal 4 after sunset. The difference in mean stomach weight of Shoals 4, 7, 8 and Shoals 5 and 6 was statistically significant in a *t*-test only at the 10-per-cent level.

Vertical migration of shoals

The depths of shoals sampled are considered here to be representative of their activity in the cycle of circadian vertical migration (Fig. 2). However, it must be cautioned that the shoals were sampled in three discrete areas and at different times. Shoals 1 — 6 were sampled from the same area on three successive days, but they were not serially sampled from dawn, through daylight and into the night. The migration pattern was therefore not actually observed (directly), but it was assumed from sample data and the corresponding findings of other authors.

BIOLOGICAL ENVIRONMENT

Phytoplankton at fish shoal positions

The percentage composition of phytoplankton present at each fish shoal position is given in Table III. Only the most important diatom species and other notable groups found are presented in Table

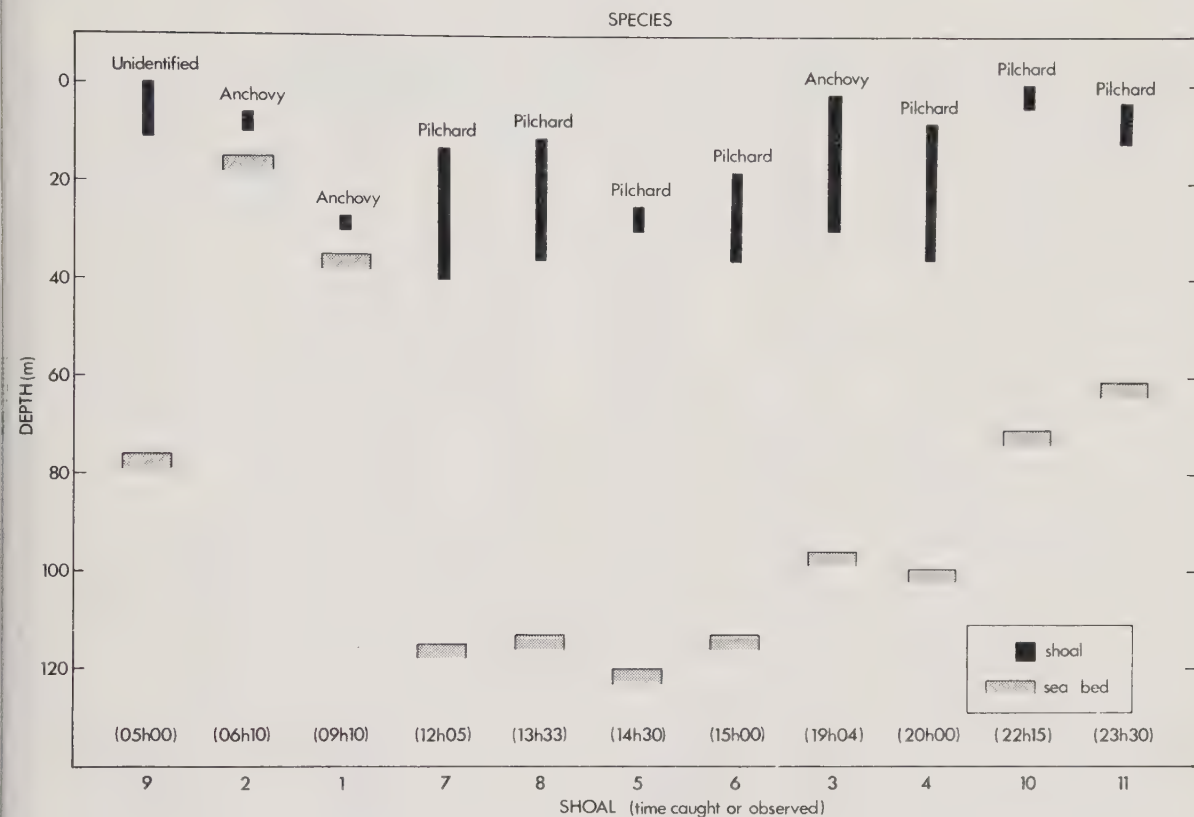


Fig. 2: Distribution of pelagic fish shoals by depth and time of day

III. The total list of species present in samples is given by taxonomic group in the Appendix.

Other than in the vicinity of Shoal 5, phytoplank-

ton density at the surface ranged between 833×10^3 and 1788×10^3 cells $\cdot \ell^{-1}$. At shoal 5, it was only 158×10^3 cells $\cdot \ell^{-1}$. In comparison, the densities at shoal

Table III: Phytoplankton composition at fish shoal positions

Phytoplankton taxon	Composition of phytoplankton at each shoal position (%)											
	1	2	3	4	5	6	7	8	9	10	11	Total
DIATOMS												
<i>Thalassiosira decipiens</i>	24,1	12,1	55,9	66,8	82,0	59,3	51,5	46,1	8,9	29,0	27,9	42,1
<i>Delphineis karstenii</i>	60,5	74,6	17,7	6,6	5,1	6,5	0,8	—	46,2	10,8	3,1	21,1
<i>Chaetoceros</i> spp.	2,5	3,7	10,4	7,8	0,7	4,1	21,2	31,4	19,4	20,7	27,4	13,6
<i>Asterionella japonica</i>	3,0	2,0	8,6	10,2	4,0	4,7	1,5	2,8	20,8	0,7	0,7	5,4
<i>Nitzschia</i> spp.	2,5	1,6	2,9	3,6	2,4	3,3	6,4	4,7	1,0	3,0	5,2	3,3
<i>Bacteriastrium delicatulum</i>	—	—	—	—	—	—	8,1	6,5	—	—	—	1,3
Rest of diatoms	2,5	3,5	2,0	2,9	4,8	4,9	9,3	7,8	3,0	18,8	14,4	6,7
OTHER GROUPS												
Dinoflagellates	0,3	0,3	0,6	1,2	0,2	1,2	0,1	0,4	0,8	16,1	20,3	3,8
Blue green algae	3,0	2,5	—	—	—	15,6	—	—	—	0,2	0,3	1,9
Flagellates (unknown)	1,2	—	1,6	—	0,2	0,1	0,5	0,1	—	—	0,4	0,4
Rest of other groups	0,4	0,2	0,4	0,6	0,1	0,5	0,2	0,3	0,1	0,7	0,6	0,4

Table IV: Environmental data at shoal sampling stations, June 1973

Shoal number	Shoal depth range (m)	Sampling depths (m)	Temperature (°C)	Salinity (‰)	Oxygen concentration (mℓℓ ⁻¹)	Phytoplankton abundance (cells-ℓ ⁻¹)	Wind	
							Speed (knots)	Direction
1	27-30	0	13,60	35,23	3,18	1 312 500	20	SSE
		5	13,60	35,23	2,83	1 840 000		
		10	13,57	35,22	2,83	625 000		
		25	13,21	35,21	1,27	369 500		
2	6-10	0	13,60	35,27	2,85	1 620 000	7	SSE
		5	13,47	35,26	2,15	2 222 000		
		10	13,22	35,25	1,25	1 962 500		
3	2-30	0	13,97	35,28	4,52	832 500	10	SSE
		5	13,93	35,27	4,26	790 000		
		10	13,90	35,27	4,26	522 500		
		20	13,65	35,27	3,42	882 500		
		30	13,51	35,26	2,19	1 682 500		
		50	13,14	35,25	0,85	360 000		
		75	12,71	35,23	0,13	37 500		
4	8-36	0	13,90	35,26	4,53	930 000	9	SSE
		5	13,89	35,20	4,47	665 500		
		10	13,82	35,26	4,17	780 000		
		20	13,70	35,24	3,70	742 500		
		30	13,60	35,27	2,84	637 500		
		50	13,21	35,25	0,83	290 000		
5	25-30	0	14,12	35,28	4,91	157 500	13	S
		5	14,10	35,25	4,93	1 512 500		
		10	14,07	35,27	4,84	1 372 500		
		20	14,05	35,29	4,84	1 202 500		
		30	14,03	35,21	4,82	1 017 500		
		50	13,74	35,23	2,41	777 500		
		75	12,59	35,17	0,78	25 000		
		115	12,04	35,12	0,50	25 000		
6	18-36	0	14,15	35,24	4,80	855 000	15	S
		10	13,86	35,21	4,63	1 067 500		
		20	13,78	35,23	3,91	845 000		
		30	13,60	35,25	3,47	750 000		
		50	13,02	35,22	0,81	665 000		
		110	12,12	35,12	0,25	265 000		
7	13-40	0	14,51	35,25	4,51	1 172 500	15	ESE
		10	14,40	35,24	4,52	939 500		
		20	14,37	35,30	4,58	997 500		
		30	14,21	35,26	3,82	657 500		
		40	13,69	35,25	1,91	675 000		
		75	12,70	35,20	0,49	197 500		
		110	12,18	35,13	0,15	17 500		
8	11-36	0	14,41	35,24	4,85	1 787 500	16	ESE
		10	14,38	35,30	4,72	2 515 000		
		20	14,25	35,28	3,99	1 540 000		
		30	13,75	35,27	2,15	895 000		
		40	13,47	35,29	1,31	635 000		
		75	12,65	35,21	0,27	102 500		
		110	12,22	35,15	0,09	67 500		

Table V: Environmental data at shoal sampling stations, April 1974

Shoal number	Shoal depth range (m)	Hydro-logical sampling depths (m)	Temperature (°C)	Salinity (‰)	Oxygen (ml·l ⁻¹)	Phytoplankton sampling depths (m)	Phytoplankton abundance (cells·haul·m ⁻¹)	Wind		
								Speed (knots)	Direction	
9	0-11	0	16,46	35,47	3,23	0-11	168,72	<1	Calm	
		5	16,42	35,46	3,38					
		11	16,44	35,48	3,22					
		20	16,36	35,50	3,26	11-50	160,15			
		30	16,30	35,47	2,91					
		50	16,08	35,47	2,17	50-70	50,25			
		70	15,80	35,52	0,62					
10	0-5	0	17,62	35,11	5,33	0-5	3,64	10	SSW	
		10	16,79	35,31	4,43					
		20	15,56	35,33	0,85	5-50	32,90			
		30	14,95	35,38	0,11					
		50	14,72	35,37	0,10	50-65	2,81			
		65	14,69	35,38	0,10					
		11	4-12	0	17,13	35,27	5,30			0-4
4	17,04			35,19	4,74	4-12	3,72			
8	16,92			35,27	4,98					
12	16,86			35,27	4,50	12-50	8,50			
20	16,47			35,28	3,47					
30	15,24			35,35	0,30					
50	14,74			35,38	0,12					
						50-60	3,43			

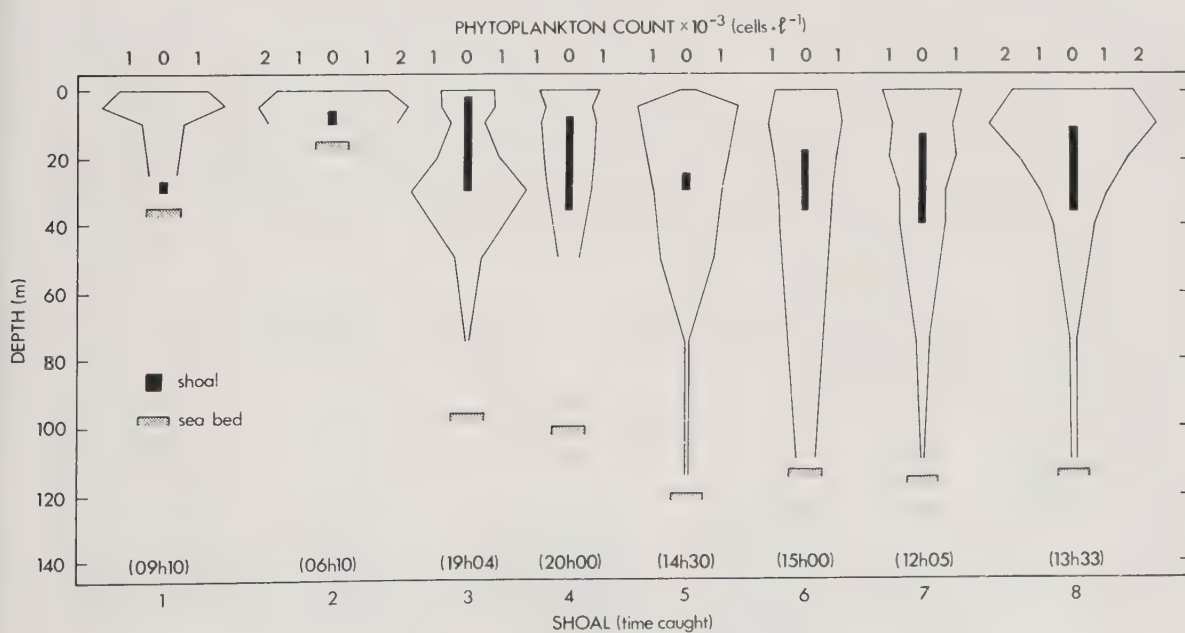


Fig. 3: Vertical distribution of phytoplankton and pelagic fish shoals, June 1973

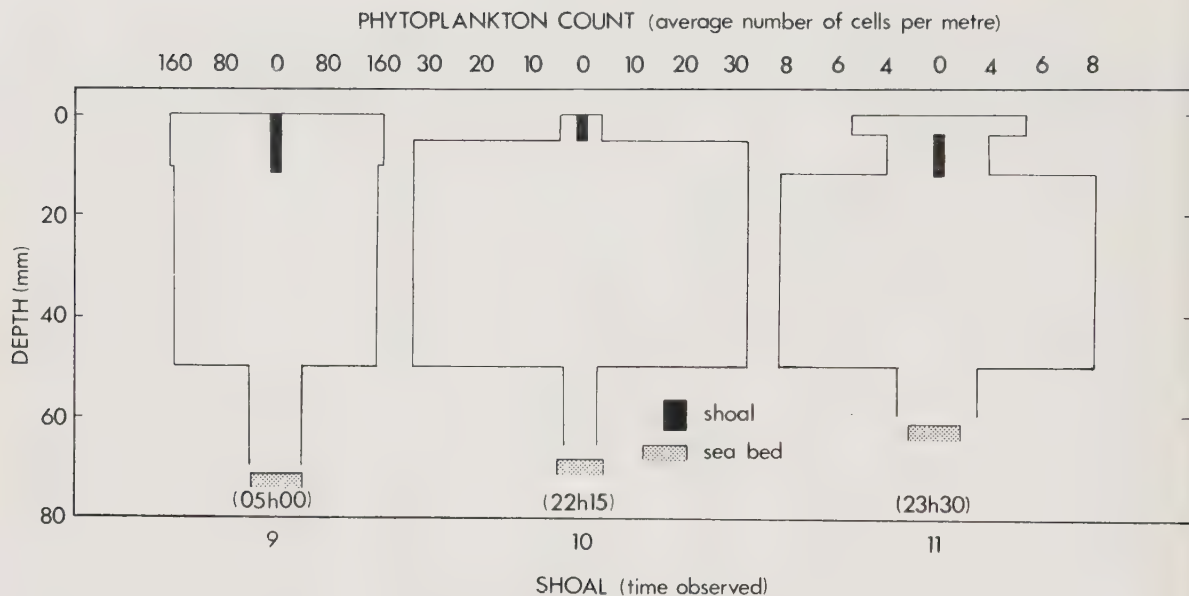


Fig. 4: Vertical distribution of phytoplankton and pelagic fish shoals, April 1974

depths (upper and lower limits) showed greater variation, ranging from 300×10^3 to $2\,500 \times 10^3$ cells $\cdot \ell^{-1}$ (Tables IV and V).

Vertical distribution of phytoplankton

Phytoplankton concentrations compared to depth are recorded in Tables IV and V and plotted with

shoal depth in Figures 3 and 4. The phytoplankton concentrations at Shoals 9 — 11 are not quantitative for individual depths because they were obtained from closing-net hauls. They are therefore not statistically comparable with the concentrations obtained quantitatively for Shoals 1 — 8.

Maximum phytoplankton standing crop was most often at 5—10 m, but at Shoals 3, 5 and 8 it was as deep as 30 m. At Shoals 4, 7 and 9 the surface

Table VI: Upper and lower limits of physical and biological parameters of fish shoals

Shoal number	Sounding (m)	Range				
		Shoal depth (m)	Temperature (°C)	Salinity (‰)	Oxygen (mℓ $\cdot \ell^{-1}$)	Phytoplankton (cells $\cdot \ell^{-1}$)
1	35	27-30	—	—	—	—
2	15	6-10	13,22-13,42	35,25-35,26	1,25-1,97	$1\,963 - 2\,169 \times 10^{-3}$
3	96	2-30	13,51-13,95	35,26-35,28	2,19-4,42	$816 - 1\,683 \times 10^{-3}$
4	100	8-36	13,49-13,85	35,24-35,26	2,23-4,29	$533 - 734 \times 10^{-3}$
5	120	25-30	14,03-14,04	35,21-35,25	4,82-4,83	$1\,018 - 1\,110 \times 10^{-3}$
6	113	18-36	13,43-13,80	35,23-35,24	2,69-4,05	$725 - 890 \times 10^{-3}$
7	115	13-40	13,69-14,39	35,25-35,26	1,91-4,54	$675 - 957 \times 10^{-3}$
8	113	11-36	13,58-14,37	35,28-35,30	1,67-4,65	$739 - 2\,418 \times 10^{-3}$
9	76	0-11	16,44-16,46	35,47-35,48	3,22-3,23	*
10	71	0-5	17,22-17,62	35,11-35,21	4,88-5,33	*
11	66	4-12	16,86-17,04	35,19-35,27	4,50-4,74	*

— Environmental data not taken to shoal depth

* Qualitative data incomparable

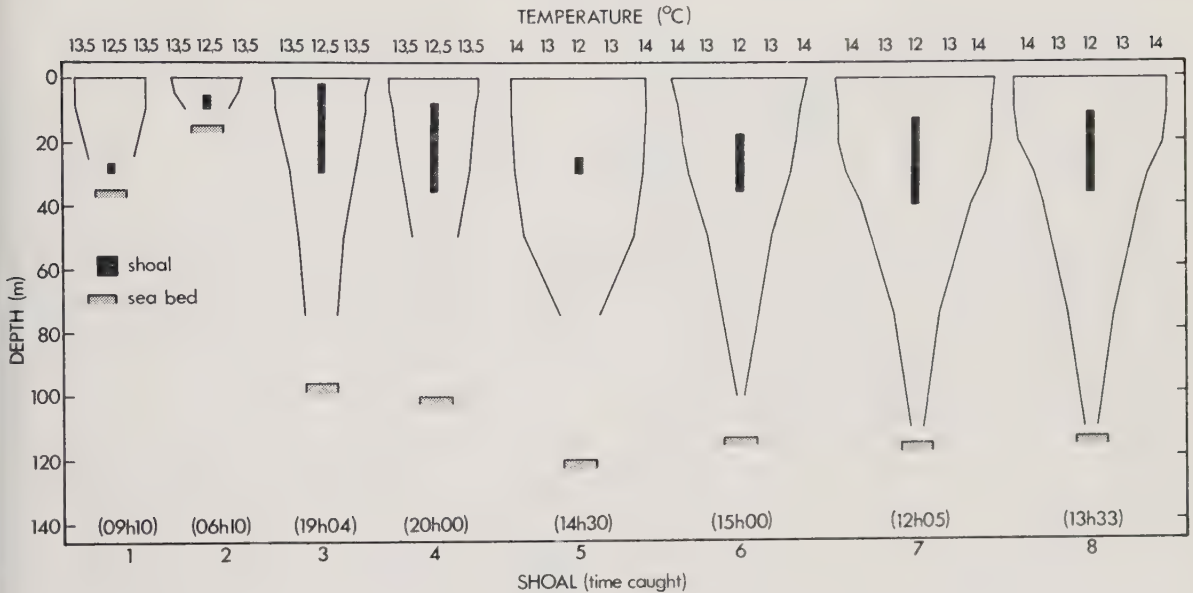


Fig. 5: Vertical distribution of temperature and pelagic fish shoals, June 1973

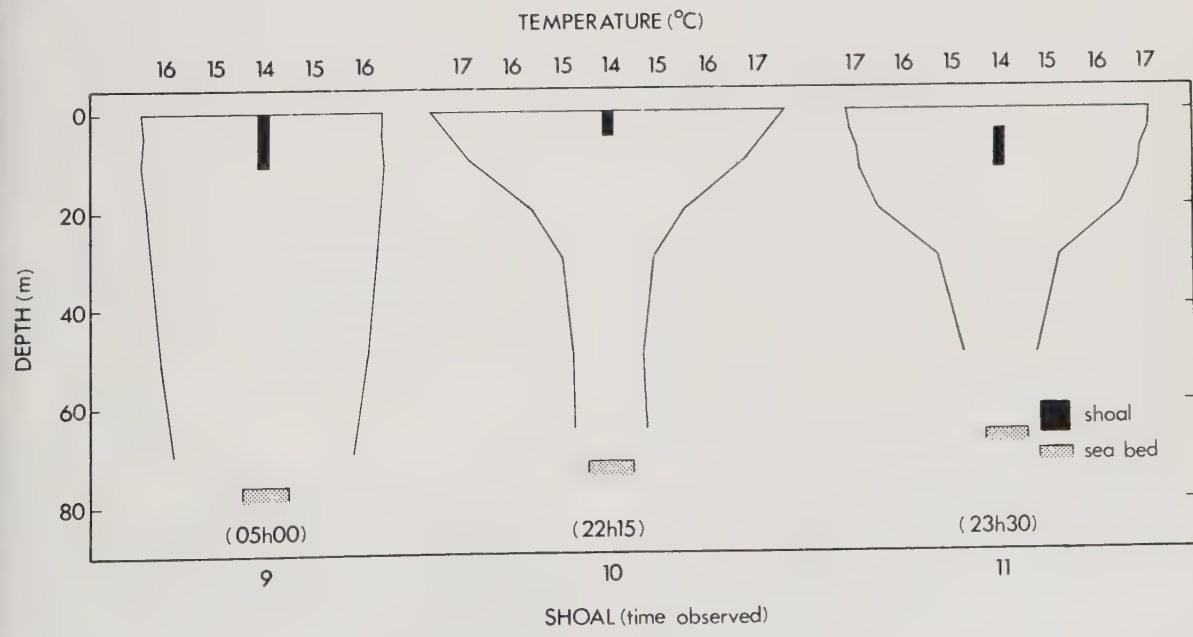


Fig. 6: Vertical distribution of temperature and pelagic fish shoals, April 1974



Fig. 7: Vertical distribution of salinity and pelagic fish shoals, June 1973

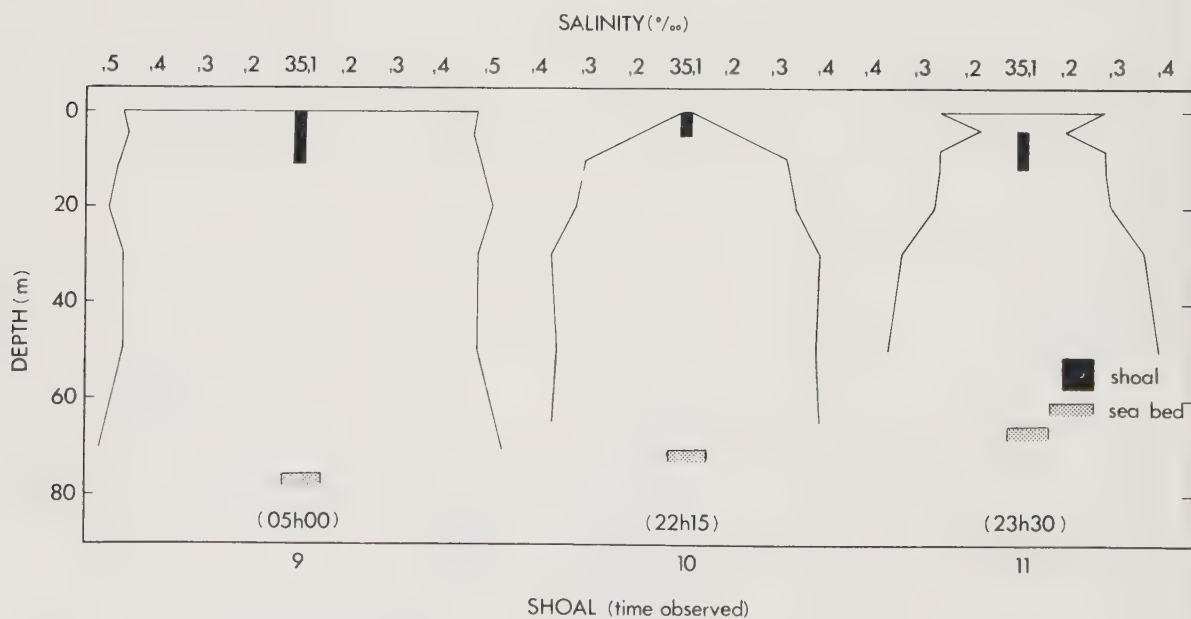


Fig. 8: Vertical distribution of salinity and pelagic fish shoals, April 1974

concentration was also the maximum.

PHYSICAL ENVIRONMENT

Temperature

Surface and subsurface temperatures of Shoals 1—8 (winter) were 2—4°C lower than those of autumn shoals (9—11)—Tables IV, V and VI. Surface temperature for both groups of shoals fluctuated within one degree, 13,60—14,51°C for the winter group and 16,46—17,62°C for the autumn group. Subsurface temperatures at the upper limits of Shoals 1—8 were not more than 0,5°C lower than at the surface and were the same as the surface temperatures associated with Shoals 9—11. Temperature differences between upper and lower limits of all shoals were slight, never being more than 0,8°C at any shoal (Table VI). Changes of temperature per metre of shoal depth at any shoal were not more than 0,1°C, suggesting that no sharp temperature gradients were endured by the fish.

The relationship between the fish shoals and the vertical distribution of temperature is presented graphically in Figures 5 (June 1973) and 6 (April 1974). The lack of any strong thermocline in either autumn or winter is clear. Where there is even a very weak thermocline present, as at Shoals 10 and 11, the fish kept well above it whereas, if lacking, the shoals extended deeper.

Salinity

The salinities associated with winter and autumn shoals are presented in Tables IV and V.

No relationship between the fish shoals and the surface and vertical distribution of salinities were found as can be seen on Figures 7 (June 1973) and 8 (April 1974).

Oxygen

Surface dissolved-oxygen concentrations close to the coast at winter Shoals 1 and 2 and autumn Shoal 9 were lower than for Shoals 3—8 further off shore near Palgrave Point in the north, but were highest for autumn shoals 10 and 11 off Henties Bay in the south (Tables IV and V).

Subsurface oxygen concentrations in shallow water at the small nearshore shoals (1 and 2) were low, varying between 1,25 and 1,97 $\text{m}\ell\cdot\ell^{-1}$. For most

other winter shoals in deeper water, oxygen concentration varied between 1,67 and 4,83 $\text{m}\ell\cdot\ell^{-1}$ (Tables IV and V). Dissolved oxygen concentration at the shoal depths was reasonably constant for the autumn (1974) shoals and for Shoal 5 (winter 1973), varying by as little as 0,01 $\text{m}\ell\cdot\ell^{-1}$ and by a maximum of 0,5 $\text{m}\ell\cdot\ell^{-1}$.

The relationship between the fish shoals and the vertical distribution of oxygen is presented graphically in Figures 9 (June 1973) and 10 (April 1974). As might be expected, dissolved oxygen concentrations decrease more gradually where no notable thermocline is present, but decrease rapidly with even the weak thermoclines of Shoals 10 and 11. These two shoals clearly occurred well above the oxyclines. Also, the minimum dissolved oxygen available to the shoals was 2,2 $\text{m}\ell\cdot\ell^{-1}$ except at Shoals 7 and 8, where the lowest concentrations were 1,9 and 1,3 $\text{m}\ell\cdot\ell^{-1}$ respectively.

Wind

Wind speed and direction are reflected in Tables IV and V. The prevalent winds were from south to east-south-east except at Shoal 10, where the wind blew from south-south-west. Wind speeds were low to moderate in the range of 7—17 knots, except at Shoal 1 where winds reached 20 knots, and at Shoal 9 where it was calm. Therefore, it is unlikely that hydrological conditions were in the process of rapid change as a result of the prevalent winds.

DISCUSSION

Agenbag (1980), in his investigation of the general distribution of pelagic fish off South West Africa, designated a winter (i.e. April—September) and a summer (i.e. October—March) distribution pattern. During winter, he found a greater frequency of shoals 18,5 km or more from the shore, whereas in summer they appeared more frequently closer to the coast. He concluded that the winter distribution was influenced by temperature and dissolved oxygen. During this survey, which was carried out in the same years and coincided with Agenbag's winter period, the off-shore distribution of the shoals conforms to his winter distribution. Shoals 1 and 2 do not conform because they were close to the coast.

The stomach weights of fish sampled, when compared with the relationship between shoal depths and phytoplankton abundances at depth presented in Figures 3 and 4, appear to indicate that both

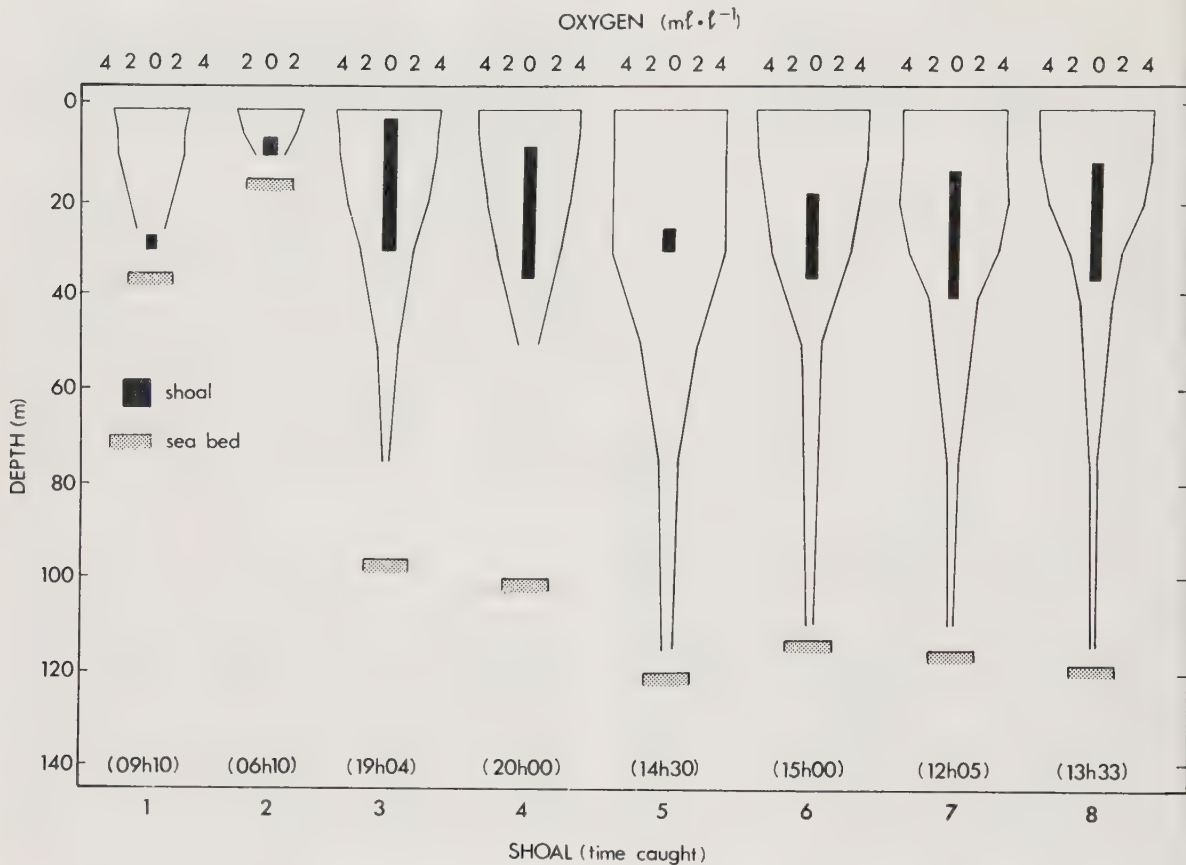


Fig. 9: Vertical distribution of oxygen concentration and pelagic fish shoals, June 1973

anchovy and pilchard feed during the day and night. However, stomach fullness and weights for anchovy were significantly higher at sunset than at dawn or early in the morning. This suggests that anchovy do more feeding in the late afternoon and evening than they do after midnight. Pilchard may follow a similar trend. Their stomach weights showed no significant difference whether caught at midday, mid-afternoon or after sunset, but because no shoals were caught in the early morning, no comparison with anchovy feeding patterns can be made here. Davies (1957) found no distinct trend of pilchard favouring night or day feeding, but his sampling was from commercial catches which were heavily biased to the night hours. According to Yoneda and Yoshida (1955), the closely related species *Sardinops melanosticta* feeds mainly during the day, but shows greater stomach weight at night off the Kyoto coast in Japanese waters.

The significant difference in stomach weight of anchovy in the spent/spent-inactive stage compared to those in active or inactive condition points towards greater feeding activity after spawning than in the pre-spawning stages. Such an increase in feeding may be to counteract the physiological drain of spawning. Pilchards did not show a highly significant difference over the three maturity stages, although Matthews (1960) stated that pilchard stop feeding at least for a short period during spawning. The results do show concentrated feeding activity by shoals with 76 per cent of their fish in the active condition around midday and after sunset, whereas those shoals feeding in mid-afternoon contained more spent/spent-inactive individuals. The data are too few to form any conclusion on what this pattern should be. It is possible that, because peak pilchard and anchovy spawning occurs at night (O'Toole

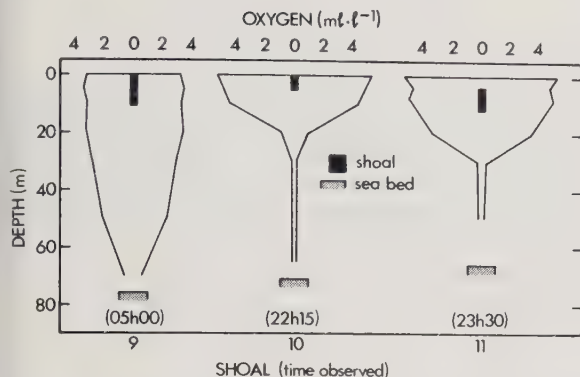


Fig. 10: Vertical distribution of oxygen concentration and pelagic fish shoals, April 1974

1977), fish active in spawning will feed mainly from midday to sunset to conserve energy and to avoid devouring their own eggs.

Good correlation has been shown between the plankton environment and the stomach contents of the South African pilchard (Davies 1957) and of the South West African pilchard and anchovy (King and Macleod 1976). The same has been shown for the Californian pilchard (Anon. 1952) and for the Japanese sardine, *S. melanosticta* (Yoneda and Yoshida 1955). Davies (*op. cit.*), Matthews (1960), Stander and Le Roux (1968) and King and Macleod (*op. cit.*) have recorded the same genera and similar species of diatoms, dinoflagellates, tintinnids and radiolarians from stomachs of South African and South West African pilchard and anchovy as recorded here (Table III). It is therefore assumed to be valid here to suggest that feeding took place from the prevalent plankton environment in which the fish were found, though detailed stomach analyses could not be carried out.

The variation between 665×10^3 and $2\,222 \times 10^3$ cells $\cdot l^{-1}$ in the phytoplankton standing crop at its average maximum depths (5 m) for the survey in both years corresponds with the $643 \times 10^3 - 3\,552 \times 10^3$ cells $\cdot l^{-1}$ found by Kollmer (1963). Figures 3 and 4 show that the uppermost parts of most shoals were located just below the maximum phytoplankton levels. Some shoals, however, extended higher than this maximum.

Diatoms were not only the most abundant group (93,5 per cent) in the environmental phytoplankton crop, but were also dominant in number of species (Table III and Appendix). *Thalassiosira decipiens*, the most important diatom species, constituted 42,1 per

cent of the phytoplankton present and was most abundant in the vicinity of Shoals 3—8.

Delphineis karstenii, a more inshore species, was also important, representing 21,1 per cent of the phytoplankton, with its greatest concentration at Shoals 1 and 2, close to the coast, and Shoal 9 (Table II and Fig. 1). *Chaetoceros* spp., which constituted 13,6 per cent of the phytoplankton made their highest contribution at Shoals 7—11. Other diatom species, such as *Asterionella japonica*, *Nitzschia* spp., *Bacteriastrum delicatulum* and the rest of the diatoms, together contributed some 17 per cent to the phytoplankton present at fish shoal positions.

Other groups constituted 6,5 per cent of phytoplankton present, of which over half were dinoflagellates (3,8 per cent). Species such as the large *Noctiluca scintillans* (diameter 200—1 200 μm) and the very small *Gymnodinium albulum* (<9 μm) were the most common dinoflagellates, especially at Shoals 10 and 11 (Table II). Blue-green algae including *Oscillatoria thiebautii* and some unidentified species made up 1,9 per cent of the phytoplankton present and were most evident at Shoal 6. Unidentified flagellates (usually very small) and the rest of the other groups (tintinnids, radiolarians, foraminiferans, silicoflagellates and coccolithophorids) together contributed about 1 per cent to the environmental phytoplankton.

Fish with significantly greater stomach masses are considered to have been actively feeding just prior to capture. Thus, the anchovy shoal caught at 19h00 is believed to have been feeding during the late afternoon, whereas the shoals caught in the early morning probably did not feed later than the previous midnight. The pilchard shoals are also considered to have been feeding during the afternoon and evening.

The shoals observed here were recorded closer to the surface during the evening and night (Shoals 2—4 and 9—11). During daylight shoals were found further away from the surface than at night (Fig. 4). Each shoal was observed only once on the day of sampling, but a circadian upward and downward migration is assumed from the uppermost depths of the shoals relative to the surface and time of day or night. Agenbag (1973) found that pelagic fish in South West Africa move deeper during the day to a maximum depth at midday or thereabout, then progressively rise to a position at or close to the surface at night. The South West African anchovy is mostly found in open, diffuse layers at or near the surface at night and in more closely packed shoals near the bottom in daytime. Pilchard do not show such a clear pattern. They are generally found in dense shoals at various distances from the surface in

the upper 50 m (R.A.C. personal observation).

There is little evidence of hydrological stimulation for vertical migration or feeding activity. The gradients of temperature around the shoals, and between the surface and any part of the shoals, were less than 1°C over differences of 10–40 m depth. The average temperature range per 10 m depth for thermoclines in South West African waters between 21 and 24°S is 2.2°C in autumn and 1.5°C in winter (Du Plessis 1967). It is clear, therefore, that, during the present study, the waters were well mixed with no strong thermoclines in either autumn or winter. The winter shoals 10 and 11 kept well above the very weak thermoclines, whereas all the other shoals extended deeper in the absence of any thermoclines.

Sea surface temperature associated with Shoals 1–8 (June 1973) ranged from 13.6 to 14.5°C, and for Shoals 9–11 (April 1974) from 16.5 to 17.6°C (Tables IV and V). Shoals 1–8 were in direct contact with subsurface temperatures of 13.2–14.4°C and Shoals 9–11 with temperatures of 16.4–17.6°C. Matthews (1960) reported that average surface temperatures in the main South West African fishing area varied from 12.3 to 14.2°C during winter and from 14.6 to 17.2°C in autumn. De Vos and Visser (1972) reported that pelagic fish were mainly present at surface temperatures below 15.5°C though occasionally as high as 17°C. Agenbag (1980) found that his winter distribution of fish shoals occurred predominantly in waters cooler than 15°C.

Strong oxyclines are distinguishable only at Shoals 10 and 11 where very weak thermoclines are also evident. In these two instances the shoals occurred in the high oxygen concentration above the thermoclines. In fact all the shoals were present in waters of high dissolved oxygen concentration whether it was limited by thermocline formation or penetrated as deep as 60 m. Surface oxygen at Shoals 1–8 varied between 2.85 and 4.91 ml·ℓ⁻¹ and from 3.23 to 5.33 ml·ℓ⁻¹ at Shoals 9–11 (Tables IV and V). This is in general agreement with the findings of De Vos and Visser (1972), who reported that pelagic fish in South West Africa were mainly found associated with a surface oxygen content of 3.5 ml·ℓ⁻¹ or greater. They reported that the highest frequency of catches (90 per cent) was in a surface oxygen concentration of 4 ml·ℓ⁻¹.

This contribution to the shoal ecology of the pilchard and anchovy off South West Africa represents only a few shoals within two limited areas observed for but a short time each. More observations are needed over a longer period to clarify the question of how shoals of these commercially important species behave in response to promptings of their diet and environmental stimuli.

ACKNOWLEDGEMENTS

We wish to thank the editor for the care and diligence with which he rearranged the report into a logical sequence. Messrs A.J. Boyd and B.B.S. Tromp are gratefully acknowledged for critically reading the report and for making useful suggestions for improvement.

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APPENDIX

Phytoplankton species present at fish shoal positions

BLUE-GREEN ALGAE

Oscillatoria thiebautii

GREEN ALGAE

Trochiscia brachiolata

EUGLENOIDS

Eutreptiella sp.

FLAGELLATES

Unidentified spp.

DIATOMS

Actinocyclus octonarius
Actinopterychus senarius
A. splendens
Asterionella japonica
Auliscus sp.
Bacteriastrum delicatulum
Biddulphia longicruris
B. mobiliensis
Cerataulina pelagica
Chaetoceros affinis
C. compressus
C. constrictus
C. convolutus
C. costatus
C. debilis
C. decipiens
C. diademus
C. didymus
C. lorenzianus
C. radicans
C. rostratus
C. socialis
Corethron criophilum
Coscinodiscus centralis
C. gigas
C. lineatus
C. radiatus
C. subtilis
Dactyliosolen mediterraneus

Delphineis karstenii
 (= *Fragilaria karstenii*)
Eucampia zoodiacus
Lauderia annulata
Leptocylindrus danicus
Melosira imbiqua
Navicula corymbosa
Nitzschia closterium
N. delicatissima
N. longissima
N. pungens
N. seriata
Paralia sulcata
Plagiogramma vanheurckii
Pleurosigma directum
P. normanni
Pseudoeunotia doliolus
Rhizosolenia alata
R. delicatula
R. fragillissima
R. imbricata
R. setigera
R. robusta
R. stouterfothii
Stephanopyxis turris
Thalassionema nitzschioides
Thalassiosira aestivalis
T. decipiens
T. eccentrica
T. polychorda
Thalassiothrix antarctica
T. delicatula
T. frauenfeldii
T. heteromorpha
Tropidoneis elegans

SILICOFLAGELLATES

Dictyocha octonaria
Mesocena polymorpha f. *octonaria*

COCCOLITHOPHORIDS

Calyptrorphaera quadridentata

DINOFLAGELLATES

Amphidinium sp.
Ceratium azoricum
C. candelabrum
C. furca
C. fusus
Cochlodinium adriaticum
Dinophysis fortii
D. rotundata
D. sphaerica
Diplopsalis lenticula
Entomosigma peridinioides
Gonyaulax minuta
G. tamarensis
Gymnodinium albulum
G. galatheanum
G. lohmanni
G. uberrimum
Gyrodinium fulvum
Noctiluca scintillans
Peridinium breve
P. conicum
P. crassipes
P. depressum
P. diabolus
P. globulus
P. inconspicuum
P. leonis
P. pellucidum
P. solidicorne
P. steinii
P. triquetrum
P. tristylum
P. trochoideum
Prorocentrum micans
Pyrophacus horologium

FORAMINIFERA

Globigerina bulloides
Globoquadrina dutertrei
Globorotalia menardii
Hastigerina pelagica
Lagena sp.
Orbulina universa

RADIOLARIA

Aulosphaera sp.
Challengeron xiphidon
Dictyophimus brandtii
Lithomelissa sp.
Phormacantha hystrix
Sticholonche zanclea

TINTINNIDS

Acanthostomella sp.
Amphorellopsis sp.
Codonellopsis contracta
C. tuberculata
Dadayiella jørgensenii
Dictyocysta speciosa
Eutintinnus pectinus
Helicostomella subulata
Metacylis jørgensenii
Parundella attenuata
P. lohmanni
Protorhabdonella curta
Rhabdonella conica
R. henssenii
R. spiralis
Salpingella decurtata
Tintinnopsis sp.

METHODS USED TO CENSUS THREE SPECIES OF SOUTHERN AFRICAN SEABIRDS, 1978-1981

P.A. SHELTON, R.J.M. CRAWFORD, F. KRIEL AND J. COOPER*

Whereas no technique for the census of seabird populations can be entirely accurate at large population sizes, consistency of methods should allow population trends to be determined. Techniques during a recent survey were kept as similar as possible to those of previous censuses. Some improvements, such as ground counts and better resolution of photographs, may cause comparatively inflated estimates and should be taken into account. A tendency for more experienced workers to record higher counts from aerial photographs must also be considered.

Hoewel geen tegniek vir die sensus van seevoëlbevolkings heeltemal akkuraat kan wees wanneer dit toegepas word op groot bevolkings nie, behoort die konstante houding van metodes dit moontlik te maak om bevolkingstendense te bepaal. Tydens 'n onlangse opname is geprobeer om tegnieke sover moontlik met dié van vorige sensusse te laat ooreenstem. Sommige verbeterings, soos grondtellings en meer beeldskerpheid in foto's, kan hoër ramings veroorsaak in vergelyking met dié wat vroeër gemaak is, en moet in aanmerking geneem word. Ook moet rekening gehou word daarmee dat meer ervare werkers geneig is om hoër tellings uit lugfoto's aan te teken.

Although population estimates of seabirds are most easily made during the breeding season, there is a disadvantage in that the non-breeding component could be omitted from the census. Total counts may be made directly, either of nests or breeding birds, with binoculars or a telescope from a suitable vantage point, or if the birds are sitting on the nest and the nests are dispersed, by walking through the colony and marking individual nest sites. With the latter method, errors in estimating the number of nests in a Massachusetts gull colony varied between 4 and 22 per cent (Erwin 1980).

If the colony is large some method of sampling, such as strip transects or quadrats, may be used, and the sample extrapolated to provide a total count on the basis of the percentage of the breeding area sampled. Randall and Ross (1979) used the mean count in 10 randomly selected areas extrapolated to the area of the colony to census Cape gannet *Sula capensis* nests on Bird Island, Algoa Bay. The sample area represented 2 per cent of the colony area. Such methods work best when the nest sites are uniformly distributed and the perimeter of the colony is clearly defined.

Aerial techniques have been widely used for the census of breeding seabirds (e.g. Boyd 1961, Barrett and Harris 1965, Kadlec and Drury 1968, Nettleship 1976, Harris and Lloyd 1977), although nesting habits such as burrowing may preclude this method for some species. Error in estimates from aerial photographs may result from observer inconsistency, difficulty in delimiting areas occupied by breeding

birds from peripheral areas used by non-breeders, distinguishing nests from birds in the breeding colony but not associated with nests, distinguishing between species, overlap or omission when building up photograph mosaics to cover colonies, aircraft disturbance, shadows and uneven or irregular substrate.

METHODS USED IN PREVIOUS SURVEYS

While no technique is entirely accurate, some degree of precision is possible and consistent methods should allow population trends to be determined. Rand (1959, 1960a,b, 1963a,b) conducted the first large-scale census of nesting Cape gannets, Cape cormorants *Phalacrocorax capensis* and jackass penguins *Spheniscus demersus* on islands and platforms off southern Africa in October and November 1956. Further, some islands were photographed in November 1967 and November 1969. In order to examine trends in the population sizes of Cape gannets, Cape cormorants and jackass penguins it was decided that a survey planned for 1978 should follow the methods of Rand (1963a) as closely as possible.

The 1956 survey was conducted during November between 10h30 and 15h30 from a South African Air Force Dakota aircraft fitted with a Wild RCA 5 camera. The camera was used to take overlapping photographs on 127 mm × 127 mm or 230 mm × 254 mm negatives (Rand 1963a). Although the

*Percy FitzPatrick Institute of African Ornithology, University of Cape Town, Rondebosch 7700, South Africa

altitude at which the photographs were taken is not specified, from examination it would appear to have been about 600 m.

Whereas Barrett and Harris (1965), Nettleship (1976) and Harris and Lloyd (1977) counted nest sites in colonies of the Northern gannet and could often distinguish whether one or two birds were in attendance, Rand (1959, 1963a) counted individual gannets which he either doubled to give a maximum theoretical population (assuming that each counted bird represented a nest site) or corrected for absenteeism, which he estimated to be 75 per cent of the mates, to obtain an estimated population size. It would appear that he did not subtract peripheral loitering immatures from the count. Boyd (1961) also counted individual birds in the St Kilda gannetry off Scotland, although paired birds could often be discerned. He felt that the low-flying aircraft (450 m) frightened some unoccupied or off-duty birds from the ledges. Boyd (*op. cit.*) pointed out that the percentage of paired birds in photographs may vary with the breeding state of the colony and the time of day of the photograph. At the St Kilda colony flocks of non-breeding mature birds were present outside the nesting area, but these appeared to be extremely mobile and numerically unstable. Boyd (*op. cit.*) considered it unlikely that many of these birds were included in the aerial photographs. In photographs of the St Kilda colony taken in 1959, sample counts gave an average of 6 per cent and a maximum of 18 per cent of the nests occupied by both birds. This finding indicates that Rand (1963a) may have been conservative in his estimate of absenteeism, although this may be explained by different altitudes of census and associated disturbance levels.

For Cape cormorants, Rand (1960b, 1963a,b) mostly counted nests which stood out as black blobs on the photographs. He assumed a high degree of absenteeism based on his observations of the widespread exodus of mates during the day. An estimate of the total colony size was obtained by doubling the number of individual black blobs counted. In some instances he differentiated roosting birds from nest sites, probably on the basis of much smaller black specks more randomly scattered rather than discretely spaced.

The jackass penguin frequently nests in burrows or in crevices between rocks and is therefore not amenable to aerial techniques on all islands, especially those with uneven, sandy or bushy substrates (Frost *et al.* 1976). In cases where aerial photographs were used, Rand's (1960a, 1963a, b) counts are considered to be of adults only. In some instances, he corrected for 75-per-cent absenteeism of mates to give a theoretical population size.

In order to count birds in the photographs taken during the 1956 survey, 60 cm × 60 cm enlargements were covered in transparent plastic and, with an illuminated magnifier, birds were marked with a pen and counted simultaneously (Rand 1963a). Mean counts were obtained from replicate estimates of counts from counts of different photographs. In a test using photographs of the gannet colony on Malgas Island, counts varied by up to 18 per cent from the mean, with an average deviation of 7 per cent (Table II of Rand *op. cit.*).

METHODS USED IN THE 1978—1981 SURVEYS

Aerial estimates

In the recent surveys an attempt was made to improve on the methods described by Rand (1963a) without losing compatibility needed for discerning trends. Photographs (e.g. Fig. 1) were taken from a South African Air Force Albatross aircraft by means of a camera with 75-mm lens and 70-mm black-and-white Ilford FP 3 film (ASA 200).

Flight trials were conducted over Malgas Island to determine the best altitude and time of day for photographs. Tests were made at altitudes of 300, 450, 600 and 900 m. Eventually 300 m was selected for the November 1978 survey because birds could be easily counted, disturbance was minimal and a large portion of the island could be covered on each negative. In the 1979 survey, photographs were taken at 600 m to facilitate colony-mapping.

Photographs taken earlier than 09h00 or later than 16h00 created shadows which made individual birds difficult to distinguish. Therefore, the survey was restricted to the intervening period, giving compatibility with the 1956 photographs which were taken between 10h30 and 15h00 (Rand 1963a).

In the case of the Cape gannet and jackass penguin, individual birds, including peripheral non-breeders, were counted on the photographs for direct comparison with the earlier counts, although in many instances nests could be clearly discerned. Often it was actually possible to tell if one or both birds were present. To obtain estimates of the population sizes of Cape cormorants (Cooper *et al.* 1982), nests, which appeared as large, regularly spaced black blobs, were counted. On some occasions counts of roosting Cape cormorants, which appeared as smaller, irregularly spaced black specks, were also made. For those islands where aerial photographs could be used to estimate the population sizes of jackass penguins, both adults and



Fig. 1: Aerial photograph of part of Ichaboe Island ($26^{\circ}17'S$ $14^{\circ}56'E$) taken at 300 m in November 1978

chicks not obscured by nesting adults were counted.

Ground estimates

Nearly all breeding localities, with the exception of those in Algoa Bay, were visited during November and December 1978 in order to demarcate the extent of the breeding colonies of the various seabird species to aid in the interpretation of aerial photographs and to count nests of jackass penguins. The islands in Algoa Bay were visited for similar purposes in December 1979. Subsequent visits to many of the

islands gave additional population estimates. In most instances, no attempt was made to count nests of Cape gannets from the ground because of the large size of the colonies and close packing of the nests. However, at Mercury Island, where small, discrete colonies occupied ledges on the otherwise precipitous terrain, nests of Cape gannets were counted directly from the ground.

Occupied nest sites of penguins were counted either by walking tightly spaced grids, by counting sectors which were divided by coloured rope, flags and natural features such as rocks and gullies, or by placing a marker at the entrance to burrows until all

nests were marked. Closely packed nest sites of penguins (surface nests) and Cape cormorants were counted from a distance of between 5 and 20 m, sometimes through binoculars, to avoid disturbance.

Nest sites were defined as paired birds defending a site, sites showing evidence of recent nest-construction (e.g. fresh seaweed or green foliage), and sites with eggs or chicks. In addition, when unattended chicks were found in groups, each group was divided by 2 for the penguin and 3 for the Cape cormorant (estimated brood sizes), and this number was taken to represent the number of nest sites. Remainders were taken to represent further sites.

Moulting jackass penguins frequently return to their nest sites (Cooper 1978), and those with moulting birds present or large accumulations of feathers were included in the counts. Nests in large colonies of Cape cormorants that could not be counted from the ground were enumerated from aerial photographs after the boundaries of the colonies had been demarcated during visits. This adjustment was considered important because, at some localities, the nest sites of Cape cormorants are mixed with those of other species such as the bank cormorant *Phalacrocorax neglectus* or the crowned cormorant *P. coronatus*. In some instances, ratios between species obtained during ground-truth surveys assisted in estimates made from aerial photographs.

A further aerial survey conducted during July 1979 was considered particularly useful for determining the size of the breeding population of Cape cormorants and jackass penguins, both of which have a variable and prolonged breeding season (Cooper 1980, Sea Fisheries Institute unpublished data). In a similar manner, subsequent visits to many of the islands yielded further information on the change in numbers with time.

ACCURACY OF COUNTS

Because aerial estimates of nests or birds were not compared with simultaneous, careful counts made on the land during the recent surveys, it is not possible to determine the accuracy of the estimates. However, some comments on accuracy, important in the determination of trends, can be made. Counts of birds in the 1978 and 1979 photographs were made in a similar manner to that described by Rand (1963a). In many cases, resolution of the 1978 photographs was superior to that of the early survey, not least because of the lower altitude at which the

Table I: A test of the accuracy of replicate counts of nests of Cape cormorants and of individual jackass penguins and Cape gannets from aerial photographs of colonies off southern Africa

Count	Cape cormorant	Jackass penguin	Cape gannet
1	3 590	2 865	4 381
2	3 726	2 849	4 722*
3	3 749	2 312	4 661*
4	3 560	2 783*	4 207
5	3 892*	2 937*	3 981†
Mean	3 703	2 749	4 390
SD	134	250	310
Range (% of mean)	8,96	22,73	16,87

* Counts made by the two experienced workers

† Count made by an inexperienced worker

photographs were taken.

Tests of the accuracy of counting of the three species on various islands in the 1978 series (Table I) show that, in five replicate counts of aerial photographs by different workers, the highest percentage standard deviation from the mean was obtained for the jackass penguin and the lowest for the Cape cormorant. The greater accuracy of the count of Cape cormorants is the result of the regular spacing of black nests against the lighter, normally flat, white, guano-covered substrate. In particular, accuracy would be expected to be higher in the case of man-made platforms. Although Siegfried (1977) found that, on several of the islands, nests of jackass penguins are arranged non-randomly in a polygonal pattern, they still do not stand out clearly on aerial photographs. In addition, nests of jackass penguins are frequently associated with surface features such as rocky ridges or bushes.

In the tests the two most experienced workers tended to obtain the highest counts (Table I). The low count for the Cape gannet colony was made by a totally inexperienced worker. A tendency for inexperienced workers to miss nest sites would result in an underestimate. It is probable that workers of a similar range of experience were used for both the 1956 and the recent surveys.

A range of 16,9 per cent of the mean for five replicate counts of the gannet colony (Table I) compares favourably with a value of 17 per cent obtained by Harris and Lloyd (1977) for the Grassholm gannetry off Wales and a value of 18 per cent obtained by Rand (1963a) for the Malgas gannetry.

Errors in aerial estimates resulting from difficulty in delimiting areas occupied by breeding birds were avoided in the recent surveys off southern Africa. Nests of Cape cormorants appeared as relatively large, regularly spaced black blobs whereas non-breeders appeared as smaller, more randomly scattered black specks. For jackass penguins and Cape gannets all individuals were counted so no delimitation was required. Error caused by the demarcation of nesting areas on photographs of the Grassholm gannetry was estimated by Barrett and Harris (1965) to be less than 2 per cent.

Errors in distinguishing between species in aerial photographs are particularly relevant to cormorants because more than one species frequently nest simultaneously and in close proximity on islands off southern Africa. In these instances nests of the Cape cormorant had to be separated by means of ground-truth information from those of the crowned cormorant, the bank cormorant and the white-breasted cormorant *Phalacrocorax carbo*. Because nearly all breeding localities were visited at the time of the census and detailed distribution maps were drawn, errors resulting from mistaken identity of species should be minimal.

Errors resulting from overlaps or omission when building up photograph mosaics of colonies have been estimated as 3.6 per cent and 5.2 per cent for two censuses of the St Kilda gannetry (Boyd 1961, and Dixon 1972 in Harris and Lloyd 1977). The corresponding errors in the estimates from the recent southern African censuses are expected to be somewhat less, because of the fairly good coverage of single colonies from photographs taken at 300 m.

No disturbance of the birds by the aircraft could be noted at this altitude. The times of the surveys were adjusted to between 09h00 and 16h00, and in most instances the substrate was fairly uniform in the vicinity of colonies of Cape gannets and Cape cormorants and to a lesser extent jackass penguins. The result is that further errors from these last three sources cannot be considered to have had a serious effect on the estimates.

Although aerial censuses of breeding seabirds are not always accurate, the use of similar techniques on replicate surveys will allow trends to be discerned. The usefulness of information on such trends goes beyond the birds themselves. Crawford and Shelton (1978, 1981) have shown that the trends in bird populations, or indices of the trends such as guano production, can be related to changes in the populations of commercially exploited pelagic fish off the southern African coast. It is foreseeable that a refinement of the relationship will allow the use of

seabirds as catch-independent indicators of concurrent changes in fish stocks.

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DISTRIBUTION, POPULATION SIZE AND CONSERVATION OF THE CAPE CORMORANT *PHALACROCORAX CAPENSIS*

J. COOPER,* R.K. BROOKE,* P.A. SHELTON AND R.J.M. CRAWFORD

The Cape cormorant *Phalacrocorax capensis* (Aves: Phalacrocoracidae) is endemic to the coast of southern Africa, breeding from Die Oase, South West Africa, to Seal Island in Algoa Bay, South Africa. The non-breeding range extends from Mayoumba, Gabon, to Delagoa Bay, Moçambique. Censuses of nests and breeding birds at all known breeding localities in the period 1977-1981 reveal that the total breeding population is approximately half a million. Historical trends in numbers show both increases and decreases related to available food supply and to breeding space. Strategies of conservation management for the species are suggested, protection of breeding localities from human disturbance and avoidance of the effects associated with severe exploitation of pelagic fish being the most important.

Die trekduiker *Phalacrocorax capensis* (Aves: Phalacrocoracidae) is endemies in suidelike Afrika en broei langs die kus van Die Oase, Suidwes-Afrika, tot by Robeiland, Algoabaai, in Suid-Afrika. Die verspreidingsgebied strek egter van Mayoumba, Gaboen, tot by Delagoabaai, Mosambiek. Uit sensusopnames van neste en broeiende voëls op alle bekende broeiplekke gedurende die tydperk 1977-1981 blyk dat die totale broeibevolking ongeveer 'n halfmiljoen is. Historiese tendense in getalle toon dat die toenames sowel as die afnames met die beskikbare voedselvoorraad en broeiruimte verband hou. Strategieë vir bewaringsbestuur van die spesie word aan die hand gedoen. Die belangrikste hiervan is beskerming van broeiereine teen versteuring deur mense, en vermyding van die gevolge wat met strawwe ontginning van pelagiese vis geassosieer word.

The Cape cormorant *Phalacrocorax capensis* (Aves: Phalacrocoracidae) is an endemic seabird of the coast of southern Africa (Clancey 1980), and it is the most numerous of southern Africa's guano-producing seabirds (Crawford and Shelton 1981). Partly because of its importance as a predator of valuable, commercially exploited, pelagic surface-shoaling fish (Davies 1955, 1956, 1958, Rand 1960, Matthews 1961, Berry 1976a, Crawford and Shelton 1978), the species has been the focus of considerable attention since the 1950's. However, knowledge of population size and fluctuations remains limited. This report covers the aspects of distribution, population size and conservation of the Cape cormorant.

METHODS

Between 1977 and 1981, most known breeding sites as well as potential nesting localities of the Cape cormorant were visited. At smaller colonies the number of nest sites was counted but, where Cape cormorants were too numerous for an accurate ground census, the extent of the distribution of each colony was plotted accurately on a map to assist with identification of species on aerial photographs. Ground counts were made of occupied nests, pairs in prenuptial plumage in a colony but not at a nest and

of unoccupied nests where no fledglings were present. At many localities Cape cormorants nest in association with other seabird species, as for example at Mercury and Ichaboe Islands (Fig. 1) where they breed next to colonies of bank cormorants *P. neglectus*. In these instances ratios of the numbers of breeding pairs of each species were ascertained, again to assist with apportioning counts made from aerial photographs. No ground-truth data were collected at Hollams Bird Island because access was difficult. Therefore, although bank cormorants also nest there in small numbers (Cooper 1981), the total count at Hollams Bird Island has been attributed to Cape cormorants.

Because the Cape cormorant breeds chiefly in the austral spring and summer (Rand 1960, Berry 1976a, McLachlan and Liversidge 1978), larger colonies were photographed from the air between 22 November and 11 December during the 1978 census. It was attempted to make this survey as simultaneous as possible, but fog caused some delay in late November, and strong winds and incomplete coverage of Dassen Island on 27 November necessitated repeat photography on 11 December. However, with the exception of Dassen and Dyer Islands, it was possible to photograph all localities having more than 1 500 pairs on 27 or 28 November. The guano platforms and the more important breeding islands off South West Africa were also photographed in July 1979 to gain insight into the

*Percy FitzPatrick Institute of African Ornithology, University of Cape Town, Rondebosch 7700, South Africa

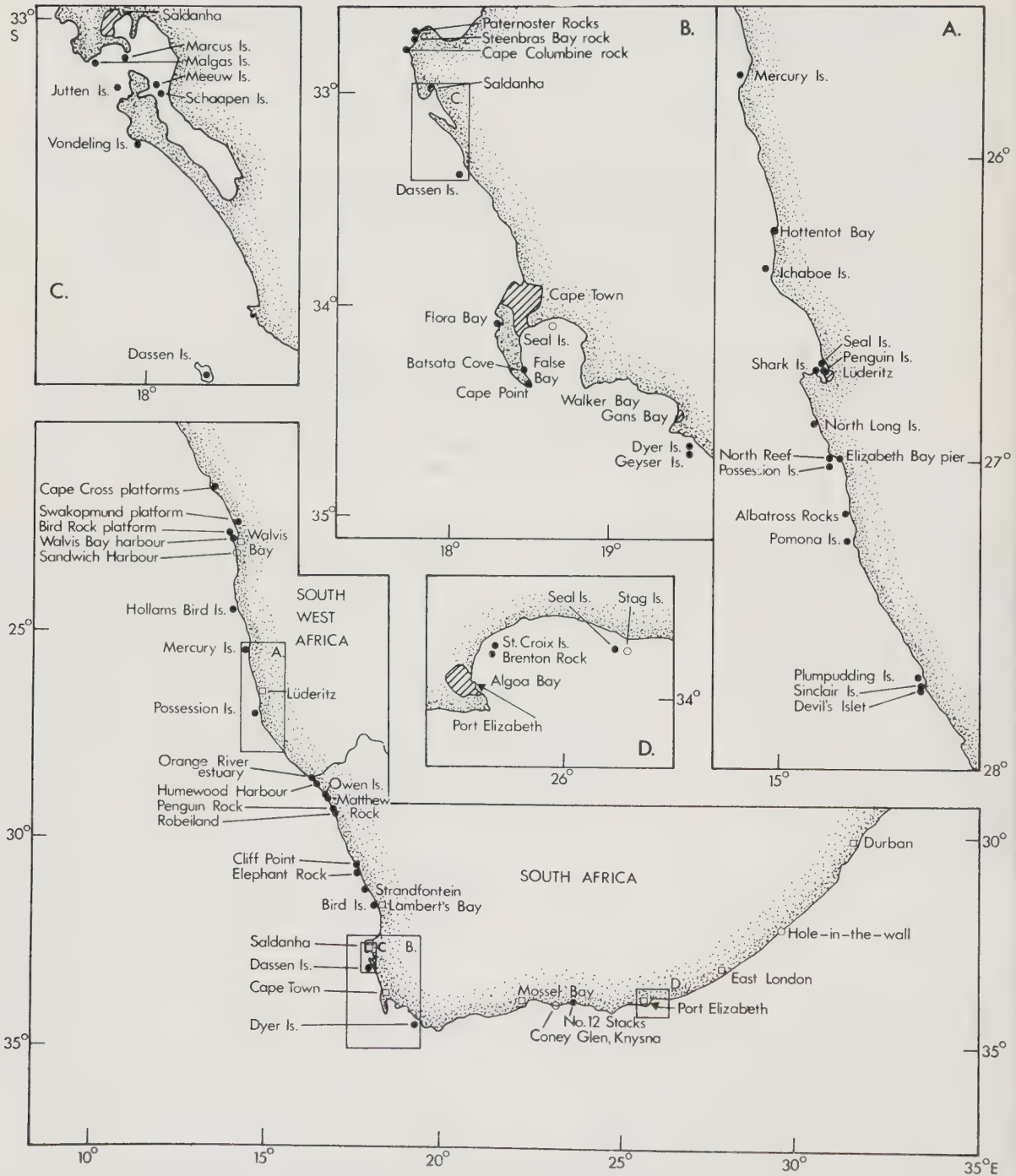


Fig. 1: Breeding localities of Cape cormorants *Phalacrocorax capensis* in southern Africa (solid circles represent localities surveyed during 1977–1981, hollow circles represent former localities not now in use)—the three northernmost colonies listed in Table I are omitted for lay-out reasons

winter distribution of Cape cormorants along that coast. Fog precluded photography of the Bird Rock guano platform.

The aerial photographs were taken by the South African Air Force under contract to the Sea Fisheries Institute. A camera fitted with a 75-mm lens mounted in the base of the aircraft was used. The film used was 70-mm Ilford FP3 with an ASA rating of 200, and the altitude at which flown was generally 300 m. In November 1978 the guano platforms were photographed during the evening, but on other occasions photographs were taken between about 09h00 and 16h00. From such procedures, it was hoped to obtain results that could be compared with those of previous surveys. Berry (1976a) preferred early morning or late afternoon for his estimates of total population size, whereas Rand (1963a,b) made use of photographs taken during the middle of the day. Nest counts are more easily made on photographs shot at or near midday, when roosting birds tend to be absent. At Mercury and Ichaboe Islands, diel fluctuations in the numbers of Cape cormorants at three breeding colonies were observed directly from the ground to investigate the impact of time of day on aerial assessments.

Aerial photographs taken during November 1967 or November 1969, again by the South African Air Force, were also available for some localities. Cape cormorants on these photographs were enumerated, aided by the ground-truth information collected in later years as a guide for species identification. The estimates are considered reliable.

The nest record cards of the Southern African Ornithological Society and published literature have been examined for further breeding records and for information on non-breeding distribution.

Census techniques are described in more detail by Shelton *et al.* (1982).

DISTRIBUTION

The known breeding distribution of the Cape cormorant extends from Die Oase (19°27'S, 12°49'E) in South West Africa to Seal Island (33°50'S, 29°17'E) in Algoa Bay, South Africa (Fig. 1). An old breeding locality at Hole-in-the-Wall (32°02'S, 29°07'E), Transkei, where a clutch was collected in 1925 or 1926 (Roberts 1934), has not been included within the present range. Several published accounts restricting the species' breeding range to the west coast of Africa (Mackworth-Praed and Grant 1962, White 1965, McLachlan and Liversidge 1978, Dorst and Mougins 1979) are incorrect. These authors have

overlooked the observations by Courtenay-Latimer and Gibson-Hill (1946) of Cape cormorants breeding at the Bird Island group.

Breeding has been observed on a sandbank in the Orange River estuary (Frost and Johnson 1977, Manry 1978), on an island in a small lake 7.5 km inland (Die Oase), and on guano platforms on coastal salt pans in South West Africa (Berry 1976a). Elsewhere the species is strictly marine, breeding on off-shore islands and rocks (Rand 1963a,b), cliffs (Taylor 1909) and on artificial structures on the coastline (e.g. Berry 1975, Siegfried and Johnson 1977).

Particularly in winter there are major movements outside the normal breeding range. Gurney (1864) reports that thousands appeared around Durban, Natal, in late 1862. It is a regular visitor in greatly varying numbers to the coasts of Natal, chiefly between July and November, right up to the Moçambique border (Cyrus and Robson 1980) and on to Delagoa Bay in southern Moçambique (Brooke *et al.* 1981). There is no evidence that the Cape cormorant occurs north of Delagoa Bay, i.e. north of 25°S on the east coast of Africa. It is not likely to be found further north regularly because it is a species of the southern subtropical zone, and the waters of the Moçambique coast are purely tropical. Few southern seabird species are found north of Delagoa Bay (Brooke *et al.*, *op. cit.*).

On the West Coast substantial movements also take place. Before guano platforms were built, Andersson and Gurney (1872) reported major influxes into Walvis Bay in June and July of birds which had left for their breeding grounds by December. The species is a regular visitor in large numbers at that time of year to the southern Angolan coast. As discussed by Brooke (1981), there were at least five deposits of accumulated guano in southern Angola, the most northerly being on the Ilhéu dos Passaros at 13°25'S in the Benguela Province. There is little doubt that these guano deposits were formed by Cape cormorants, probably non-breeding visitors from the south. North of Lobito, where the waters are clearly tropical (Briggs 1974), the Cape cormorant is only a vagrant. Chapin (1932) thought he saw a few in the Congo estuary on 30 January, but he did not formally include them in the avifauna of Zaire. The species was collected at Landana in Cabinda in the last century (Malbrant and Maclatchy 1949). These authors also observed several birds in a lagoon near Pointe Noire, Democratic Republic of the Congo, on 21 January 1943. The most northerly record known to us is of a bird collected near Mayoumba on the south coast of Gabon (Chapin *op. cit.*), where the species has not been reported since

(Rougeot 1948).

Cape cormorants have been recorded up to 70 km off shore, but few occur more than 20 km from the coast (Siegfried *et al.* 1975). The species commonly roosts and bathes in coastal estuaries and wetlands, foraging at times in the former (Brown 1905, personal observation). Sick and starving Cape cormorants, usually juveniles, are often seen up to 10 km from the sea and away from water (Crawford *et al.* 1980, J.C. personal observation). These individuals quickly succumb.

POPULATION SIZE AND TRENDS

A total of 277 032 nest sites was counted at 51 localities (Table I, Fig. 1) based on the largest census made at each locality in the period 1977–1981. A further five localities are known from before the census period (Appendix 1). The census of nest sites represents an estimated breeding population of 554 064 birds, of which 212 958 (38,4 per cent) occurred at 27 localities in South Africa (south of the Orange River) and 341 106 (61,6 per cent) at 24 localities in and off South West Africa. However, because the islands off South West Africa are a political part of South Africa, only 148 546 (26,8 per cent) birds at eight localities fall under the jurisdiction of South West Africa. A total of 481 652 breeding birds (86,9 per cent) was found at the localities west of Cape Point in the Atlantic Ocean and 72 412 birds (13,1 per cent) in the Indian Ocean on the East Coast. Large breeding populations were recorded north of Walvis Bay, on islands near Lüderitz, in Saldanha Bay and at Dyer Island (Table I, Fig. 1).

A feature of the census results is the large populations calculated for the guano platforms. Rand (1963b) suggested a possible population of 675 000 on the Cape Cross central platform and 240 000 on the Bird Rock platform in 1956. However, these figures were criticized by Berry (1976a), because they were based on faulty assumptions concerning platform size and the area requirements of roosting Cape cormorants. Therefore, they have not been incorporated in Appendix 1. Instead, recounts from the original photographs are given, but because the photographs were taken during the middle of the day they probably underestimate the total number of birds in the vicinity. Berry (*op. cit.*) estimated a combined platform population of 465 000 — 1 053 000 individuals in 1973–1974, and he considered the higher value to be the more realistic assessment. In November 1978, 74 471 nests were counted at the platforms, representing

approximately 150 000 individuals.

It is apparent that insight into trends in these northern populations is essential before any comment on changes in the overall status of the Cape cormorant is possible. The four platforms at which Cape cormorants were breeding in 1978 were all constructed between 1930 and 1963, although at the Cape Cross northern platform additional space was provided as recently as 1971. However, even before the existence of platforms large numbers of the species were present in the Walvis Bay region (Andersson and Gurney 1872). Large numbers of cormorants were observed by Meinertzhagen (1950) at Pelican Point in 1949, but the figures he gives are questionable (Cooper 1981).

Gevers (1936), writing about the Cape Cross lagoon, commented: "The lagoon is inhabited by thousands of flamingoes and hundreds of thousands of cormorants which roost on low islets in the lagoon and are the cause of the accumulation of quantities of guano." A total of 200 000 short tons of guano was removed from these islets between 1895 and 1903, but it is uncertain whether the deposits were old or fairly modern (Rand 1952b). This quantity of guano is exceptionally large when compared with more recent production at the platforms (Appendix 2). Between 1923 and 1944 annual guano harvests from sand islands in Sandwich Harbour ranged between 236 and 2 240 short tons, i.e. 214–2 033 metric tons (Rand *op. cit.*). At both Cape Cross lagoon and Sandwich Harbour, silting and other factors later caused the islands to join the mainland and rendered them unsuitable for breeding and roosting (Rand *op. cit.*).

Therefore, erection of guano platforms may be regarded as having provided alternative breeding localities for Cape cormorants, following topographical changes in the Cape Cross lagoon and at Sandwich Harbour that destroyed the isolation of natural sites. In fact, the construction of platforms was presumably precipitated by the decreasing guano deposits at islands in these two lagoons.

It is difficult to assess population trends from the available census information. Numbers of Cape cormorants at breeding sites exhibit diel fluctuations (Berry 1976a, Fig. 2) and colonies are characterized by considerable year-to-year variations in breeding size. For instance, 7 873 nests were photographed on an island in the Orange River estuary on 11 December 1976 (Frost and Johnson 1977), but none was present on 28 November 1978. On 17 November 1981 c. 250 nests were counted at this locality, but an estimated 10 000 birds in breeding plumage were prospecting for nest sites. Other notable examples of annual variation include Bird Rock platform, Mercury Island and Ichaboe Island (Appendix 1).

Table 1: Distribution of breeding localities and maximum numbers of Cape cormorants *Phalacrocorax capensis* at each, 1977-1981

Locality	Date	Number of nest sites	Source
Die Oase	30 Nov. 1981	c. 75	
Terrace Bay	summer 1979/80	c. 20	R. Loutit <i>in litt.</i>
4 km south of Torra Bay	24 Jan. 1981	2	R. Loutit <i>in litt.</i>
Cape Cross northern platform	28 Nov. 1978	4 944	
Cape Cross central platform	28 Nov. 1978	25 653	
Swakopmund platform	28 Nov. 1978	43 542	
Bird Rock platform	28 Nov. 1978	332	
Walvis Bay harbour	13 Dec. 1981	8	
Hollams Bird Island	28 Nov. 1978	109	
Mercury Island	30 Jan. to 02 Feb. 1980	8 840	
Hottentot Bay	10 Dec. 1979	present	B. Smith <i>in litt.</i>
Ichaboe Island	03 to 07 Feb. 1980	45 805	
Seal Island, Lüderitz	28 Nov. 1978	21 457	
Penguin Island	28 Nov. 1978	18 292	
Shark Island	01 Aug. 1977	32	P.D. Shaughnessy*
North Long Islands	01 Dec. 1978	30	
Elizabeth Bay pier	early Dec. 1977	5	Siegfried and Johnson 1977
North Reef	01 Dec. 1978	1 177	
Possession Island	02 to 04 Dec. 1978	83	
Albatross Rock	06 to 08 Dec. 1978	9	
Pomona Island	23 Jan. 1980	35	
Plumpudding Island	23 Jan. 1980	25	
Sinclair Island	23 Jan. 1980	20	
Devil's Islet	08 Dec. 1978	58	
South West Africa		170 553	(24 localities)
Orange River estuary	17 Nov. 1981	c. 250	
Stacks south of Humewood Harbour	19 Nov. 1981	88	
Owen Island	19 Nov. 1981	1	
Matthew Rock	21 Nov. 1981	c. 405	
Penguin Rock	21 Nov. 1981	4	
Robeiland	20 Nov. 1981	182	
Stack south of Cliff Point	08 Mar. 1980	124	
Elephant Rock	08 Apr. 1979	67	
Strandfontein	27 Dec. 1980	4	L.G. Underhill*
Bird Island, Lambert's Bay	27 Nov. 1978	13 519	
Paternoster Rocks	06 Jan. 1979	6	
Steenbras Bay rock	29 Sep. 1981	25	P.A.R. Hockey*
Cape Columbine rock	02 Jan. 1981	18	H.G. Robertson*
Malgas Island	27 Nov. 1978	8 708	
Marcus Island	31 Dec. 1981	5	A.M. Griffiths*
Meeuw Island	20 Nov. 1978	55	
Schaapen Island	18 Jul. 1979	207	
Jutten Island	27 Nov. 1978	24 277	
Vondeling Island	27 Nov. 1978	7 890	
Dassen Island	11 Dec. 1978	13 767	
Flora Bay	14 Jul. 1981	28	
Cape Point	30 Jan. 1981	643	
Batsata Cove	07 Jun. 1981	9	
Dyer Island	22 Nov. 1978	35 580	
Geyser Island	28 Dec. 1979	c. 210	
No. 12 Stacks, Tsitsikamma Coastal National Park	30 Oct. 1980	75	
St Croix Island	27 Oct. 1978	208	Randall <i>et al.</i> 1981
Brenton Rock	15 Nov. 1980	c. 80	Randall <i>et al.</i> 1981
Seal Island, Algoa Bay	09 Nov. 1977	44	Randall <i>et al.</i> 1981
South Africa		106 479	(27 localities)
Total		277 032	(51 localities)

* Nest record card

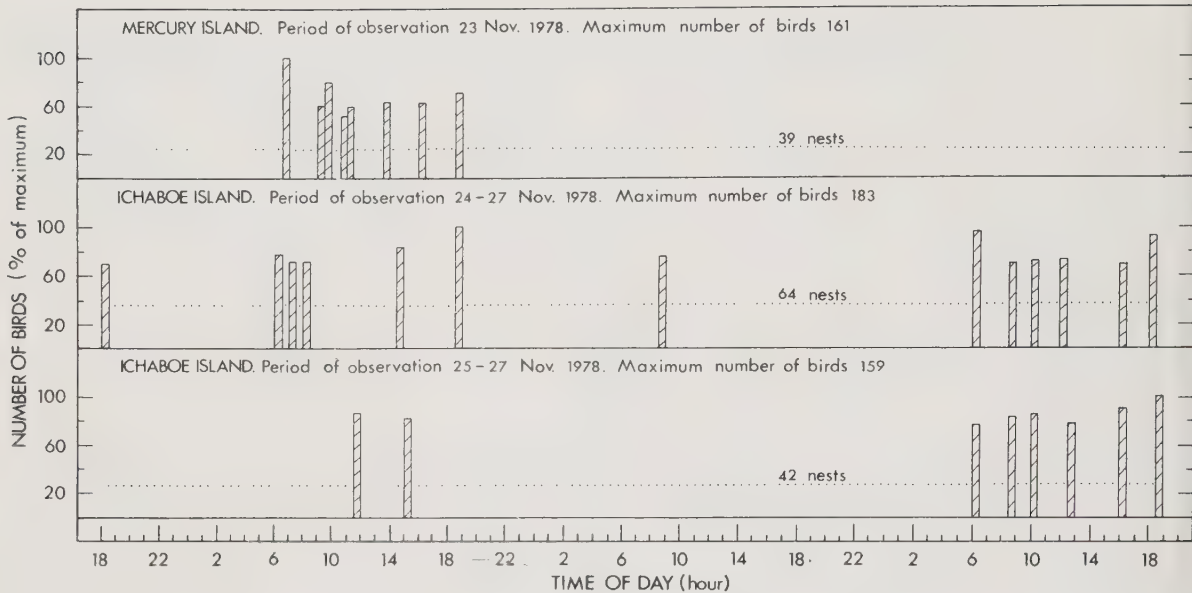


Fig. 2: Fluctuations in observed numbers of Cape cormorants *Phalacrocorax capensis* at breeding localities as a function of time of day

However, in a number of regions in southern Africa it has been demonstrated that guano-production is closely linked to seabird abundance (Crawford and Shelton 1978).

Guano harvests at the South West African platforms for the period 1931-1978 are given in Appendix 2. Cape cormorants are the dominant guano-producers on these platforms (Rand 1963b, Berry 1975, 1976a), where the harvest was considerably higher in 1973 (3 611 metric tons) than in 1950 (1 247 tons), but notably low in 1978 (916 tons). These figures suggest that the population of Cape cormorants at the platforms was larger in 1973 than in 1956, but that it subsequently decreased. Such trends have been ascribed to an increase in the combined platform surface area during the 1960's and early 1970's, followed by a severe decrease in the biomass of the South West African pilchard *Sardinops ocellata* in the late 1970's (Crawford and Shelton 1981). It is noteworthy that the ratio of the estimated population size of Cape cormorants in spring 1973 to the guano harvest of that year (144:1) is similar to the corresponding ratio for 1978 (123:1). Therefore, the two surveys appear to have yielded compatible results and the techniques employed could be used as a basis for future assessments in the area.

At islands, use of guano figures as an index of

population size is complicated by the presence of large concentrations of other seabirds. Moreover, simultaneous surveys to estimate total numbers which provide adequate coverage either during the early morning or evening would be both expensive and difficult, because of the wide distribution of breeding populations and the possibility of large numbers of birds roosting on the mainland coastline. Berry (1977) has commented on the fidelity of Cape cormorants to nesting area, and we consider that the best way of monitoring future changes in the total population of Cape cormorants is to census nests at the main breeding localities in mid-season. Breeding populations at Mercury, Ichaboe, Seal (Lüderitz), Penguin and Dyer Islands were considerably larger in 1978 than in 1956 (Appendix 1). These trends have been related to food availability (Crawford and Shelton 1981).

Rand (1949) commented on an annual migration of Cape cormorants in January, when large numbers were observed passing Sinclair Island in a northerly direction, and many immature birds rested on the island. In the early 1950's, observations suggested that Cape cormorants ranged well to the south of Walvis Bay in summer, but that during autumn and winter they congregated in the vicinity of the platforms (Rand 1952b). This pattern is borne out by censuses conducted in 1978 and 1979 (Table II). In

Table II: Spring-summer and winter populations of Cape cormorants *Phalacrocorax capensis* off South West Africa, 1978-1979

Locality	Parameter censused	Number of birds	
		Spring-summer 1978-1979	Winter 1979
Cape Cross northern platform	Nests	4 944	0
	Roosting birds	7 261	10 157
		12 205	10 157
Cape Cross central platform	Nests	25 653	
	Roosting birds	5 195	
		30 848	
Swakopmund platform	Nests	43 542	0 ⁺
	Roosting birds	19 361	757 ⁺
		62 903	757 ⁺
Bird Rock platform	Nests	332	No estimate
	Roosting birds	5 923	No estimate
		6 255	No estimate
Mercury Island	Nests	5 890	Few*
	Roosting birds	2 363	Few*
		8 253	Few*
Ichaboe Island	Nests	21 695	Few*
	Roosting birds	4 100	Few*
		25 795	Few*
Seal Island, Lüderitz	Nests	27 457	3 071
	Roosting birds	161	232
		27 618	3 303
Penguin Island	Nests	18 292	298
	Roosting birds	111	37
		18 403	335
North Reef	Nests	1 177	No estimate

⁺ Platform being scraped on day of census

* Accurate census difficult, but species noticeably absent in comparison with other photographs of same island

spring and summer there were extensive breeding populations at the platforms, as well as at Mercury, Ichaboe, Seal (Lüderitz) and Penguin Islands and North Reef, but in winter the species was only abundant north of the islands. Off South West Africa upwelling is most conspicuous in the area between Lüderitz and the Orange River, decreasing in intensity further north, and it attains its maximum in late winter and spring (Stander 1964). It has been postulated that the mature component of the South West African pilchard population undertakes a southerly migration at this time (Schülein 1971). Therefore, the seasonal distributions of Cape cormorants and pilchards off South West Africa are

similar, and the pattern evidenced by Cape cormorants is probably in some measure a response to food availability.

CONSERVATION

The Cape cormorant has not been regarded as a candidate for conservation management in southern Africa, as have two sympatric species, bank and crowned cormorants *P. coronatus* (Siegfried *et al.* 1976). The last two species occur in far smaller numbers, and they are considered to be vulnerable to disturbance at their breeding colonies but not especially at risk to either oiling or competition with the fishing industry (Cooper 1981, Crawford *et al.* 1982). The whitebreasted cormorant *P. carbo* also occurs in smaller numbers and is considered to be vulnerable to disturbance while breeding (Brooke *et al.* in press).

Rowan (1969) lists the Cape cormorant as being affected by oil spills. However, only 30 (7.8 per cent) of 385 individuals received at a seabird rehabilitation centre in Cape Town over a five-year period were oiled (Morant *et al.* 1981). Of 1 491 birds found dead on beaches in the South-Western Cape on monthly beach patrols of the African Seabird Group from February 1977 to June 1981, none was significantly oiled (G. Avery, South African Museum, *in litt.*). Cape cormorants are susceptible to oiling by fish oil originating as waste from fishmeal factories. Separate incidents at Walvis Bay and Bird Island, Lambert's Bay, resulted in the oiling of an estimated 9 500 individuals (Anon. 1974, Berry 1976b). Improvement in techniques of fish off-loading, with a switch from a wet to a dry method, has apparently reduced this risk.

Cormorants are susceptible to disturbance while breeding (e.g. Kury and Gochfeld 1975), and the Cape cormorant is no exception. Nest desertion and subsequent egg and chick loss to predators such as the kelp gull *Larus dominicanus* can occur when colonies are approached too closely, especially in the early stages of breeding (Jarvis and Cram 1971, personal observation). Access to all island colonies and any human disturbance is prohibited by law, although some activity such as guano-collection and seal-culling is permitted by concession and under supervision. The law cannot adequately be enforced at all localities, especially at those islands which are remote and do not have headmen to enforce the law. Although guano-collection is known to cause disturbance to breeding seabirds in southern Africa (Berry *et al.* 1974, Hockey and Hallinan 1981), this

activity cannot be considered to be a serious threat at present population levels of Cape cormorants.

Human disturbance may take the form of the permanent loss of breeding habitat. Continuing harbour activities at Bird island, Lambert's Bay, have resulted in the loss of approximately one-third of the available suitable breeding habitat. Elsewhere, especially on the guano platforms of South West Africa, breeding habitat has been increased. The species is protected in terms of the Sea Birds and Seals Protection Act, 1973, in that landing without permit is prohibited on scheduled islands. This protection should be extended to all known breeding localities.

Cape cormorants may desert their breeding colonies for other reasons, often related to the food supply (Crawford *et al.* 1980). The Cape cormorant feeds on surface shoaling fish of commercial importance (Rand 1960, Crawford and Shelton 1978, Cooper in press) and, unlike the other sympatric cormorants, it may be affected by competition with a commercial fishery. However, Crawford and Shelton (1981) show that there has been an increase in the number of Cape cormorants in recent years, followed by a subsequent decrease. Commercial fishing has led to a reduction in the available prey size as is shown by the enforced switch of the industry from the pilchard to the smaller anchovy *Engraulis capensis*. Severe exploitation of the remaining resources of small pelagic fish such as the anchovy may lead to further decreases in numbers of Cape cormorants. Such decreases would occur by a reduction in recruitment rates as shortage of food causes mass nest desertion and breeding failure (e.g. Crawford *et al.*, *op. cit.*).

When decisions are made on the management of pelagic surface-shoaling fish populations in southern Africa, the conservation management of the Cape cormorant should not be ignored.

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APPENDIX 1

Schedule of counts of Cape cormorants *Phalacrocorax capensis* at breeding localities

Date	Time	Census technique	Parameter censused	Number	Source
<i>Die Oase 19°27'S, 12°42'E</i>					
30 Nov. 1981	09h30	ground count	nests	c. 75	
			roosting birds	c. 800	
<i>Terrace Bay 19°59'S, 13°02'E</i>					
Summer 1979/80	—	ground count	nests	c. 20	R. Loutit <i>in litt.</i>
<i>4 km S of Torra Bay (wreck of the Henrietta Spachette) 20°21'S, 13°15'E</i>					
24 Jan. 1981	—	ground count	nests	2	R. Loutit <i>in litt.</i>
27 Nov. 1981	09h30	ground count	nests	1	
			roosting birds	107	
<i>Toscanini 20°49'S, 13°23'E</i>					
23 Dec. 1976	—	ground estimate	nests	present	C.F. Clinning ‡
<i>Cape Cross 31°46'S, 13°57'E northern platform</i>					
20 Nov. 1956	10h30-15h30	aerial photography	nests	0	
			roosting birds	0	
28 Nov. 1978	16h30	aerial photography	nests	4 944	
			roosting birds	7 261	
10 Jul. 1979	10h13	aerial photography	nests	0	
			roosting birds	10 157	
<i>Cape Cross central platform</i>					
20 Nov. 1956	10h30-15h30	aerial photography	nests	9 426	
			roosting birds	5 792	

APPENDIX I *continued*

Date	Time	Census technique	Parameter censused	Number	Source
28 Nov. 1978	16h35	aerial photography	nests	25 653	
			roosting birds	5 195	
10 Jul. 1979	10h20	aerial photography	nests	0	
			roosting birds	20 377	

Cape Cross all platforms combined

20 Nov. 1956	10h30-15h30	aerial photography	nests	9 426	
			roosting birds	5 792	
1 Mar. 1973	09h45	aerial photography*	population	25 000	Berry 1976a
26 Mar. 1973	16h30	ground estimate*	population	193 000	Berry 1976a
13 Sep. 1973	13h30	ground estimate*	population	193 000	Berry 1976a
27 Jun. 1974	17h30	aerial photography*	population	900 000	Berry 1976a
28 Nov. 1978	16h30-16h40	aerial photography	nests	30 597	
			roosting birds	12 456	
10 Jul. 1979	10h15-10h25	aerial photography	nests	0	
			roosting birds	30 534	

Swakopmund platform 22°36'S, 14°31'E

1 Mar. 1973	09h15	aerial photography*	population	270 000	Berry 1976a
26 Mar. 1973	18h00	ground estimate*	population	734 000	Berry 1976a
13 Sep. 1973	11h30	ground estimate*	population	325 000	Berry 1976a
27 Jun. 1974	18h00	aerial photography*	population	3 000+	Berry 1976a

APPENDIX I *continued*

Date	Time	Census technique	Parameter censused	Number	Source
28 Nov. 1978	17h10	aerial photography	nests	43 542	
			roosting birds	19 361	
10 Jul. 1979	10h45	aerial photography	nests	0+	
			roosting birds	757+	

Bird Rock platform 22°53'S, 14°32'E

20 Nov. 1956	10h30-15h30	aerial photography	nests	2 569	
			roosting birds	2 229	
1 Mar. 1973	09h00	aerial photography*	population	170 000	Berry 1976a
26 Mar. 1973	08h30	ground estimate*	population	85 000	Berry 1976a
13 Sep. 1973	10h00	ground estimate*	population	3 000	Berry 1976a
27 Jun. 1974	18h15	aerial photography*	population	150 000	Berry 1976a
28 Nov. 1978	16h00	aerial photography	nests	332	
			roosting birds	5 923	

All South West Africa/Namibia platforms combined

20 Nov. 1956	10h30-15h30	aerial photography	nests	11 995	
			roosting birds	8 021	
1 Mar. 1973	09h00-09h45	aerial photography*	population	465 000	Berry 1976a
26 Mar. 1973	08h30-18h00	ground estimate*	population	1 012 000	Berry 1976a
13 Sep. 1973	10h00-13h30	ground estimate*	population	521 000	Berry 1976a

APPENDIX I *continued*

Date	Time	Census technique	Parameter censused	Number	Source
27 Jun. 1974	17h30-18h15	aerial photography*	population	1 053 000	Berry 1976a
20 Nov. 1978	16h00-17h10	aerial photography	nests	74 471	
			roosting birds	37 740	
<i>Walvis Bay harbour 22°57'S, 14°30'E</i>					
13 Dec. 1981		ground count	nests	8	
<i>Sandwich Harbour 23°20'S, 14°28'E</i>					
11 Jan. 1971		ground count	nests	15	H.H. Berry
<i>Hollams Bird Island 24°38'S, 14°32'E</i>					
Apr.-May 1951		visit	nests	0	Rand 1952a
			roosting birds	present	
Nov. 1956		aerial photography	nests	215▲	Rand 1963 (recounted)
			roosting birds	163▲	
18 Dec. 1976		aerial photography	nests	152▲	
			roosting birds	3 359▲	
25 Mar. 1977		photograph from boat	nests	14	P.D. Shaughnessy <i>in litt.</i>
			roosting birds	586	
28 Nov. 1978	14h15	aerial photography	nests	109▲	
			roosting birds	592▲	
<i>Mercury Island 25°43'S, 14°50'E</i>					
20 Nov. 1956	10h30-15h30	aerial photography	nests	1 540	
			roosting birds	3 240	

APPENDIX I *continued*

Date	Time	Census technique	Parameter censused	Number	Source
15 Nov. 1967		aerial photography	nests	few■	
			roosting birds	few■	
25 or 26 Nov. 1969		aerial photography	nests	few■	
			roosting birds	few■	
28 Nov. 1978	13h45	aerial photography	nests	5 890	
			roosting birds	2 363	
9 Jul. 1979	14h15	aerial photography	nests	few■	
			roosting birds	few■	
30 Jan. - 2 Feb. 1980		ground count	nests	8 840	

Hottentot Bay 26°08'S, 14°57'E

10 Dec. 1979		ground survey	nests	present	B. Smith <i>in litt.</i>
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Ichaboe Island 26°17'S, 14°56'E

20 Nov. 1956	10h30- 15h30	aerial photography	nests	present	Rand 1963b
			individuals	353	
15 Nov. 1967		aerial photography	nests	3 213	
25 or 26 Nov. 1969		aerial photography	nests	105†	
28 Nov. 1978	13h30	aerial photography	nests	21 695	
			roosting birds	4 100	
9 Jul. 1979	14h00	aerial photography	nests	few■	
			roosting birds	few■	
3-7 Feb. 1980		ground count	nests	45 805	

APPENDIX I *continued*

Date	Time	Census technique	Parameter censused	Number	Source
<i>Seal Island, Lüderitz 26°36'S, 15°09'E</i>					
20 Nov. 1956	10h30-15h30	aerial photography	nests	1 028	Rand 1963b
28 Nov. 1978	13h08	aerial photography	nests	21 457	
			roosting birds	161	
9 Jul. 1979	13h45	aerial photography	nests	3 071	
			roosting birds	232	
19 Jan. 1980		ground count	nests	c. 50	
<i>Penguin Island 26°37'S, 15°09'E</i>					
20 Nov. 1956	10h30-15h30	aerial photography	individuals	0	Rand 1963b
26 Jan. 1976		ground count	nests	c. 5 000	Shaughnessy and Shaughnessy 1978
28 Nov. 1978	13h00	aerial photography	nests	18 292	
			roosting birds	111	
9 Jul. 1979	13h45	aerial photography	nests	298	
			roosting birds	37	
19 Jan. 1980		ground count	adults	12 780	
<i>Shark Island 26°38'S, 15°09'E</i>					
1 Aug. 1977		ground count	nests	32	P.D. Shaughnessy ‡
<i>North Long Islands 26°49'S, 15°07'E</i>					
1 Dec. 1978		ground count	nests	30	
<i>Elizabeth Bay pier 26°55'S, 15°12'E</i>					
10-18 Dec. 1976		aerial observations	nests	c. 200	Frost and Johnson 1977
1-7 Dec. 1977		ground count	nests	5	Siegfried and Johnson 1977

APPENDIX I *continued*

Date	Time	Census technique	Parameter censused	Number	Source
<i>North Reef 27°00'S, 15°11'E</i>					
1 Dec. 1978		ground count	nests	1 177	
26 Jan. 1980		ground count	nests	630	
<i>Possession Island 27°01'S, 15°12'E</i>					
c. 1956		observations	occasional roosters	not indicated	Rand 1963b
2-4 Dec. 1978		ground count	nests	83	
22 Jan. 1980		ground count	adults	5 335	
<i>Albatross Rock 27°07'S, 15°14'E</i>					
6-8 Dec. 1978		from boat	nests	9	
23 Jan. 1980		from boat	nests	0	
<i>Pomona Island 27°12'S, 15°16'E</i>					
7 Dec. 1978		ground count	nests	15	
23 Jan. 1980		ground count	nests	33	
<i>Plumpudding Island 27°39'S, 15°31'E</i>					
c. 1956		observations	breeding birds	few	Rand 1963b
8 Dec. 1978		ground count	nests	14	
23 Jan. 1980		ground count	nests	25	
<i>Sinclair Island 27°40'S, 15°31'E</i>					
8 Dec. 1978		ground count	nests	0	
23 Jan. 1980		ground count	nests	20	
4 Feb. 1980		ground count	nests	5	
<i>Devil's Islet 27°40'S, 15°31'E</i>					
1946		observations	breeding pairs	5	Rand 1949
1947		observations	successful pairs	1	Rand 1949
8 Dec. 1978		through binoculars from Sinclair Island	nests	58	

APPENDIX I *continued*

Date	Time	Census technique	Parameter censused	Number	Source
<i>Orange River estuary 28°38'S, 16°26'E</i>					
11 Dec. 1976		aerial photography	nests	7 873	Frost and Johnson 1977
22-28 Apr. 1978		ground count	nests	7	Manry 1978
			disused nests	6	
26 Apr. 1978	16h30-18h30	ground observations	roosting birds	22 000	Manry 1978
28 Nov. 1978	11h10	aerial photography	nests	0	
			roosting birds	0	
17 Nov. 1981		ground estimates	nests	c. 250	
			roosting birds	c. 10 000	
<i>Stacks south of Humewood Harbour 28°46'S, 16°34'E</i>					
14 Jan. 1980		ground count	nests	24	
19 Nov. 1981		ground count	nests	88	
<i>Owen Island 29°16'S, 16°52'E</i>					
19 Nov. 1981		ground count	nests	1	
<i>Matthew Rock 29°17'S, 16°52'E</i>					
21 Nov. 1981		count from shore	nests	c. 405	
<i>Penguin Rock 29°34'S, 17°00'E</i>					
21 Nov. 1981		count from shore	nests	4	
<i>Robeiland 29°34'S, 17°00'E</i>					
17 Jan. 1980		ground count	nests	50	
20 Nov. 1981		ground count	nests	182	
<i>Stack south of Cliff Point 31°36'S, 18°07'E</i>					
21 Jan. 1980		ground count	nests	10	
8 Mar. 1980		ground count with telescope	nests	124	

APPENDIX I *continued*

Date	Time	Census technique	Parameter censused	Number	Source
<i>Elephant Rock 31°39'S, 18°09'E</i>					
8 Apr. 1979		count from shore	nests	67	
			individuals	c. 350	
21 Jan. 1980		count from shore	nests	32	
			individuals	219	
10 May 1980		count from shore	nests	1	
<i>Strandfontein 31°46'S, 18°14'E</i>					
27 Dec. 1980		ground count	nests	4	L.G. Underhill ‡
<i>Bird Island, Lambert's Bay 32°05'S, 18°18'E</i>					
23 Nov. 1956	10h30-15h30	aerial photography	individuals	30 977	Rand 1963a
15 Jan. 1963		ground count	nests	700	B.W. Rowlands ‡
29 Mar. 1964		ground count	nests	410	B.W. Rowlands ‡
13 Nov. 1967		aerial photography	nests	9 698	
c. 1970		observations	breeding pairs	c. 30 000	Jarvis and Cram 1971
27 Nov. 1978	13h00	aerial photography	nests	13 519	
			roosting birds	10 284	
24-25 Jul. 1979		ground count	nests	0	
23 Aug. 1979		ground count	nests	0	
27 Sep. 1979		ground count	nests	1 766	
25 Oct. 1979		ground count	nests	c. 7 580	
27 Nov. 1979		ground count	nests	c. 9 604	
21 Dec. 1979		ground count	nests	c. 2 778	
8 Jan. 1980		ground count	nests	c. 969	

APPENDIX I *continued*

Date	Time	Census technique	Parameter censused	Number	Source
<i>Paternoster Rocks 32°44'S, 17°53'E</i>					
c. 1956		observations	individuals	few	Rand 1963a
6 Jan. 1979		ground count	nests	6	
			individuals	704	
<i>Steenbras Bay Rock 32°45'S, 17°54'E</i>					
12 Jan. 1981		count from shore	nests	6	L.G. Underhill ‡
29 Sep. 1981		count from shore	nests	25	P.A.R. Hockey ‡
<i>Cape Columbine rock 32°49'S, 17°51'E</i>					
2 Jan. 1981		count from shore	nests	18	H.G. Robertson†
<i>Malgas Island 33°03'S, 17°55'E</i>					
Oct. 1956	10h30-15h30	aerial photography	individuals	14 547	Rand 1963a
23 Nov. 1956	10h30-15h30	aerial photography	individuals	0	Rand 1963a
10 Nov. 1967		aerial photography	nests	1 861	
			roosting birds	34	
25 or 26 Nov. 1969		aerial photography	individuals	5 538	
27 Nov. 1978	10h00	aerial photography	nests	8 708	
			birds	3 211	
18 Jul. 1979		ground count	nests	0	
22 Aug. 1979		ground count	nests	0	
26 Sep. 1979		ground count	nests	453	
23 Oct. 1979		ground count	nests	14	
26 Nov. 1979		ground count	nests	108	
20 Dec. 1979		ground count	nests	21	
9-10 Jan. 1980		ground count	nests	6	

APPENDIX I *continued*

Date	Time	Census technique	Parameter censused		Number	Source
<i>Marcus Island 33°03'S, 17°58'E</i>						
9 Jun. 1951			85 chicks ringed			E.H. Ashton SAFRING
Oct. 1956	10h30-15h30	aerial photography	roosting birds		1 000	Rand 1963a
23 Nov. 1956	10h30-15h30	aerial photography	individuals		0	Rand 1963a
Summer 1973/4		ground estimate	nests	c.	250	
27 Nov. 1978	10h05	aerial photography	nests		0	
			roosting birds		130	
17-18 Jul. 1979		ground count	roosting birds	c.	3 500	
31 Dec. 1981		ground count	nests		5	A.M. Griffiths‡
<i>Meeuw Island 33°05'S, 18°00'E</i>						
29 Sep. - 4 Oct. 1963		ground count	nests	c.	40	B.W. Rowlands‡
20 Nov. 1978		ground count	nests		55	
18 Jul. 1979		ground count	nests		29	
<i>Schaapen Island 33°06'S, 18°01'E</i>						
29 Sep. - 6 Oct. 1963		ground count	nests		56	B.W. Rowlands‡
30 Dec. 1963		ground count	nests		137	B.W. Rowlands‡
20 Nov. 1978		ground count	nests		141	
18 Jul. 1979		ground count	nests		207	
<i>Jutten Island 33°05'S, 17°57'E</i>						
23 Nov. 1956	10h30-15h30	aerial photography	nests		27 757	Rand 1963a
			total individuals		28 135	
27 Nov. 1978	09h50	aerial photography	nests		24 277	
			roosting birds		33 606	

APPENDIX I *continued*

Date	Time	Census technique	Parameter censused	Number	Source
<i>Vondeling Island 33°09'S, 17°59'E</i>					
23 Nov. 1956	10h30-15h30	aerial photography	disused nests	8 300	Rand 1963a
			individuals	798	
10 Nov. 1967		aerial photography	nests	95	
27 Nov. 1978		aerial photography	nests	7 890	
			roosting birds	615	
<i>Dassen Island 33°25'S, 18°05'E</i>					
23 Nov. 1956	10h30-15h30	aerial photography	nests	0	Rand 1963a
Mar. 1957		unspecified	individuals	11 760	Rand 1963a
Summer 1957-1958		observations	breeding birds	dense numbers	Rand 1963a
11 Dec. 1978	16h10	aerial photography	nests	13 767	
			roosting birds	15 120	
<i>Flora Bay 34°03'S, 18°22'E</i>					
14 Jul. 1981		ground count	nests	28	
<i>Cape Point 34°21'S, 18°30'E</i>					
3 Sep. 1963		ground count	nests	75	D.M. Skead\$
20 Aug. 1980		ground count	nests	634	
30 Jan. 1981		ground count	nests	643	
<i>Batsata Cove 34°17'S, 18°28'E</i>					
17 Jun. 1981		ground count	nests	9	
<i>Seal Island, False Bay 34°08'S, 18°35'E</i>					
16 Nov. 1931		ground count	nests	few	Wyndham 1932
<i>Dyer Island 34°41'S, 19°25'E</i>					
22 Nov. 1956	10h30-15h30	aerial photography	individuals	3 186	Rand 1963a

APPENDIX I *continued*

Date	Time	Census technique	Parameter censused	Number	Source
22 Nov. 1978	09h15	aerial photography	nests	35 580	
			roosting birds	10 813	
14-16 Jun. 1979		ground observations	nests	0	
			roosting birds	0	

Geyser Island 34°42'S, 19°25'E

22 Nov. 1956	10h30-15h30	aerial photography	individuals	264	Rand 1963a
19 Oct. 1978		ground count	nests	0	
17 Jun. 1979		ground observations	nests	0	
28 Dec. 1979		ground count	nests	c. 210	
			roosting birds	0	

Coney Glen, Knysna 34°05'S, 23°03'E

5 Jun. 1973		observation from shore	nests	present	E.O. Pike‡
1 Jan. 1974		observation from shore	nests	present	E.O. Pike‡

No. 12 stacks, Tsitsikamma Coastal National Park, 33°59'S, 23°36'E

30 Oct. 1980		ground count	nests	75	
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St Croix Island 33°48'S, 25°46'E

27 Oct. 1978		ground count	nests	208	Randall <i>et al</i> 1981
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Brenton Rock 33°49'S, 25°46'E

15 Nov. 1980		count from boat	nests	c. 80	Randall <i>et al.</i> 1981
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Seal Island, Algoa Bay 33°50'S, 26°17'E

9 Nov. 1977		ground count	nests	44	Randall <i>et al.</i> 1981
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Stag Island 33°50'S, 26°17'E

Nov. 1936		ground count	nests	6	Courtenay-Latimer and Gibson-Hill 1946
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APPENDIX I continued

Date	Time	Census technique	Parameter censused	Number	Source
<i>Hole-in-the-Wall 32°02'S, 29°07'E</i>					
1925 or 1926		ground observation	nests	min. 1	Roberts 1934

* Calculated as area occupied by roosting birds (m²) x 25

+ Platform being scraped on day of census

▲ No ground-truth information for identification of species. Entire count attributed to Cape cormorants

■ Accurate assessment difficult but species noticeably scarce in comparison with other photographs of same island

† Not all island photographed

‡ Nest record card

APPENDIX 2

Guano production (metric tons) at the northern and central Cape Cross, Swakopmund and Bird Rock platforms, 1931-1978

Year	Cape Cross northern	Cape Cross central	Swakop-mund	Bird Rock	Total	Year	Cape Cross northern	Cape Cross central	Swakop-mund	Bird Rock	Total
1931	—	—	—	8	8	1957	—	611	—	611	1 222
1932	—	—	—	24	24	1958	—	775	—	924	1 699
1933	—	—	—	43	43	1959	—	778	—	853	1 631
1934	—	—	—	71	71	1960	—	651	—	770	1 421
1935	—	*	—	82	82 ⁺	1961	—	857	—	700	1 557
1936	—	*	—	143	143 ⁺	1962	—	726	—	997	1 723
1937	—	170	—	162	332	1963	102	997	241	819	2 159
1938	—	1 462	—	207	1 669	1964	67	286	82	983	1 418
1939	21	1 469	—	230	1 720	1965	103	339	912	611	1 965
1940	—	1 353	—	412	1 765	1966	—	373	929	771	2 073
1941	167	1 674	—	713	2 554	1967	107	540	1 130	582	2 359
1942	218	1 199	—	903	2 320	1968	—	582	746	469	1 797
1943	5	1 978	—	723	2 706	1969	118	1 169	—	299	1 586
1944	13	783	—	759	1 555	1970	216	718	1 034	250	2 218
1945	36	*	—	875	911 ⁺	1971	482	501	—	562	1 545
1946	94	688	—	883	1 665	1972	198	836	807	582	2 423
1947	64	1 352	—	807	2 223	1973	219	871	2 095	426	3 611
1948	59	364	—	616	1 039	1974	213	493	—	413	1 119
1949	—	358	—	552	910	1975	—	541	1 782	455	2 778
1950	—	*	—	577	577 ⁺	1976	225	267	1 748	484	2 724
1951	—	455	—	559	1 014	1977	—	518	649	678	1 845
1952	—	527	—	905	1 432	1978	397	—	—	519	916
1953	—	547	—	806	1 353						
1954	—	580	—	871	1 451						
1955	69	669	—	814	1 552						
1956	43	421	—	783	1 247						

* Figures no longer available

+ Figures exclude Cape Cross central platform

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